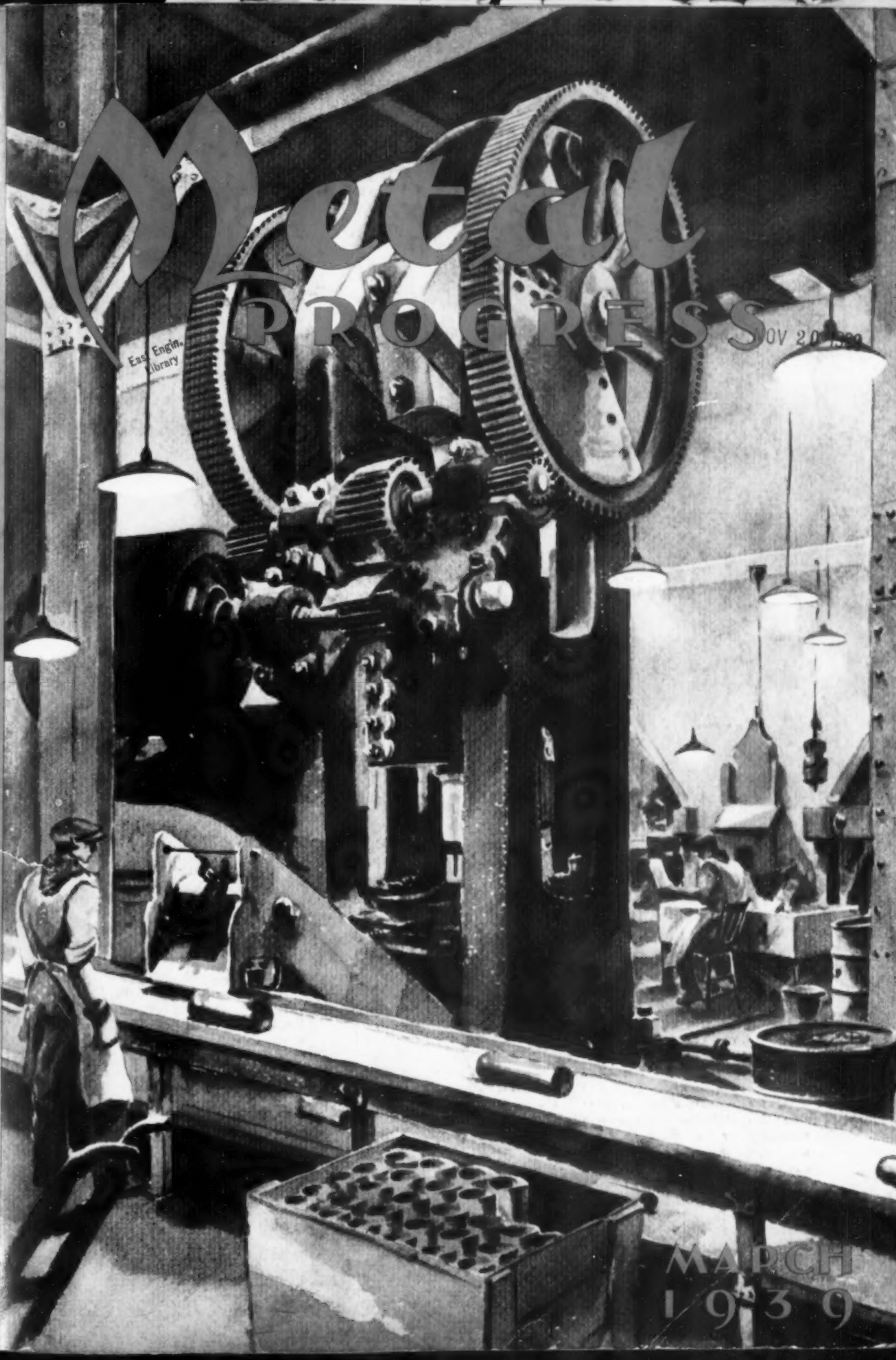
AMERICAN SOCIETY FOR METALS



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LARGE STEEL FORGINGS — NOTES ON MODERN MANUFACTURE

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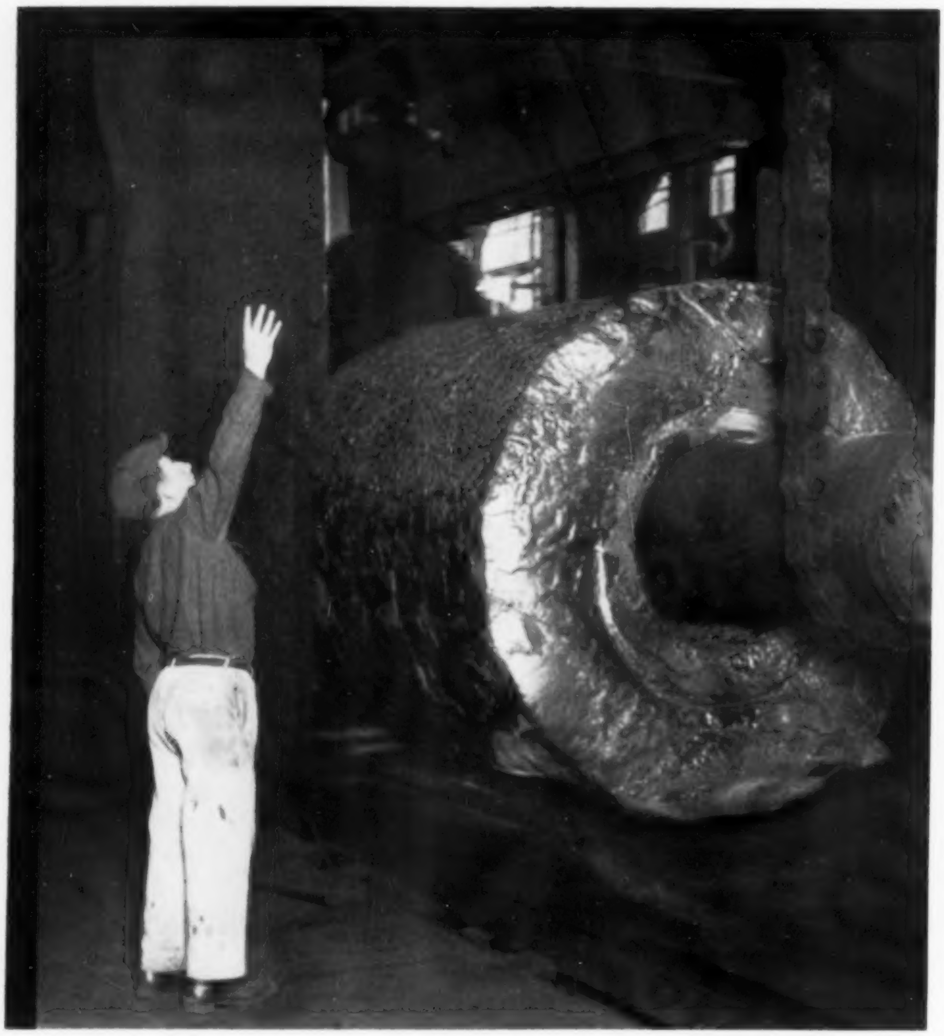
SINCE it is the style to start an article with a brief historical note — perhaps to establish paternity of unsullied blood — it may be remarked that forging is one of the most ancient arts. Indeed it is very plausible that before it was possible to produce a fluid metal and to cast it into molds, ore was reduced to a pasty mass in forge fires, slag and dross were hammered out on the anvil, and a forged iron article shaped for use. The size of pieces was increased by merely hammer welding additional lumps to the original piece. This primitive method of iron manufacture was practised for centuries without material change. Indeed, the principal difference in the manufacturing methods for the famous Delhi Pillar, a 17-ton wrought iron forging made in the third or fourth century, and two 40-ton shafts made for the S.S. Adriatic in 1856 by Reading Steam Forge Co., is that in the latter case steam did the hammering. The following account is quoted:

"The shafts of the Adriatic were forged in 12 working days each on a 7-ton steam hammer. They were commenced on what is called a porter bar, forming a tapering handle, to which are attached levers or cranks to turn the shaft in its slings while under the hammer. The porter bar was first heated, and then flattened at its thick end to receive a pile of bloom bars each about 250 lb. weight, all of which were welded solid with each other and the bar, thus forming the commencement of the 27½-in. shaft itself. The end of the shaft thus commenced was again heated to receive another pile of bars as already described, and the same process thus repeated until the shaft was 37½ ft. long, as required. When the completed portion of the shaft becomes sufficiently long, the porter bar is cut off, and the turning cranks attached to the shaft itself."

In the seclusion and privacy of the steel family, there is often heard a variation of "Which came first, the chicken or the egg?" Forgers claim their difficulties would be negligible if they were supplied with good steel to work on. Melters protest that the best steel in the world can be ruined by poor handling. For such occasions we offer the suggestion that in times not long ago forgers did without melters. We suppose they had their troubles even then!

The end of the 18th century and the beginning of the 19th witnessed a series of inventions which materially altered iron and steel manufacture. The most important of these were (1) the invention of grooved rolls for rolling, (2) invention of the puddling furnace and process,



"Up! Up!" Is the Title of This Photograph, Made (as Are the Others in This Article) by John P. Mudd for The Midvale Co.

(3) improvements in the manufacture of crucible cast steel, (4) use of the hot blast for blast furnaces, (5) increasing use of coal and coke for iron and steel melting, (6) the steam hammer, (7) the bessemer process, and (8) the Siemens-Martin or openhearth process. The date of this last invention was 1864.

By that time the mechanical revolution had invaded the iron and steel industry, and heavy forgings were made from correspondingly large steel ingots.

At any rate, since 1881, when a 17-ton steam hammer in Pittsburgh was regarded as the largest in the United States, if not in the world, the progress in forging manufacture has been rapid. This progress may be summarized as follows: Hammers became larger and larger until they became public nuisances as well as expensive and cumbersome. The steam or hydraulic press appeared, and its advantages were quickly realized. Forgings became larger and larger until they reached a maximum set by transportation facilities. Special requirements now call for special alloys. We are living in an age of forgings ordered *à la carte*, each made for a specific application, usually to have very definite properties as well as a specified chemical analysis.

The Ingot

In view of its importance we can start a discussion of present-day forgings at the ingot. It is designed to be an ideal, sound casting. The mold may be of polyhedral cross-section, tapered big-end-up, with a refractory lined hot top or sinkhead. All the causes of headaches in the foundry have been removed, as far as possible, in the design of the ingot mold, yet there is still much to be learned about the solidification of steel in large masses.

Such problems bring up thoughts of shrinkage both primary and secondary, columnar crystals, equiaxed crystals, corner concentrations and entrapped impurities. Lest we become too impressed with the deficiencies of our "ideal" casting, it is well to recall that it is possible to cast a 450,000-lb. ingot of most of the commercial alloy steels now on the market, and this ingot can be heated and forged, and the product heat treated. While it is healthy to see ahead of us a long road of needed improvements, it is not well to forget progress we have already made.

The steel for present-day large forging is melted generally in the openhearth furnace, either acid or basic. Electric furnace steel may also be used. The steel melter can be depended upon to supply heats of the desired analyses, properly conditioned. His great contribution to the manufacture of our product is the knowledge necessary to pour our "ideal" casting. No contribution can be greater.

The forger has turned over to him, however, a comparatively delicate product. Large ingots are filled with internal strains set up in cooling. The segregation of impurities toward the center of mass is likely to be quite pronounced. The desired effect of mold chill cannot be counted on. Large ingots naturally have a coarse struc-

ture, the result of pouring at a necessarily high temperature and cooling very slowly. Such large ingots should be stripped immediately after solidification, and charged while hot into heated furnaces or soaking pits.

Some consideration must be given to the dimensions of the ingot needed for a particular forging. From the steel melter's point of view it is wise to concentrate on a few standard sizes which experience indicates are best for the requirements of the usual business. The melter more readily develops skill in the production of these ingots of standard size.

The ingot selected by the forger from those he has available must be large enough to make the desired forging with sufficient discard from both ends, but not so large as to be wasteful. It should be of such a shape that sufficient mechanical work will be required on it to develop the properties desired in it, but no more. Mechanical working is extremely beneficial in increasing the physical properties of the metal in the direction of the working, but if carried to the extreme, the physical properties in other directions begin to suffer. Another deterrent to increasing the ingot size is the fact that segregation increases with the size of the ingot, together with the coarseness of the crystal structure, and the frequency of non-metallic inclusions.

Before proceeding to heat such ingots for forging, it is well to soak them for a long time at temperatures below the steel's plastic range; it is then safe to raise the temperature slowly. Ingots should be thoroughly soaked at forging temperature before they are put on the die. The largest ingots often require over 100 hr. for this first heating.

Large ingots, full of internal strains, and of extremely coarse crystal structure, are sensitive to temperature changes. If they are not to be forged immediately, steps must be taken to improve their condition so they may be safely stored. There is no better way to do this than to do some forging work on them, and then to anneal them, for the hot mechanical work is more effective than any heat treatment in refining the microstructure, and a refined structure is better able to adjust itself to temperature changes.

Although forgings — even large iron ones — have been made from ancient times, modern practice has developed in the last 75 years with the use of hydraulic presses and cast steel ingots. Most technical problems arise from the unavoidable segregation and coarse crystallization in large ingots and the difficulties of heating and heat treating — introducing or extracting heat rapidly into such large masses of metal.

The largest forgings are now made in hydraulic presses. Presses of 10,000 tons capacity squeeze and knead a 200-ton ingot into a useful article of commerce. It is difficult to imagine hammers of equal capacity. Large presses make this important contribution to the art of mechanical working — they enable the forger to knead and work large masses of metal to the very center. Steam hammers have by no means been discarded. They are, of course, extensively used to manufacture smaller forgings.

After all, size of a part is only a relative matter, and there are many who would say that *large* forgings are still being made under steam hammers in the form of disks and rings and other similar shapes whose section is not too thick, although the weight may be considerable.

The technique of forging has altered only in refinement from that of a half-century ago. Experience has taught the need for care in the initial handling of large ingots. Developing metallurgical science has rationalized the data acquired about forging temperatures and times. Expanding fields for larger forgings have called for complex alloy steels. The mechanical arts have created apparatus for the efficient manipulation of large masses. Speedier handling enables us to forge more sensitive steels. Fundamentally, however, the process has remained practically the same for 50 years.

Forging a Large Shaft

Large steamship shafts are still made as forgings. Such forgings are today usually of medium carbon steel or of nickel steel. Other large shafts are used for hydro-electric developments, for sugar mills, for generator rotors, and for mining and crushing machinery.

Such shafts probably require the simplest forging procedure. The first operation on these,

as well as on most other shapes, is to round up the ingot by a series of light squeezes over its entire surface. Such work accomplishes the most important task of consolidating the central portion and incidentally begins the refinement of the columnar crystals which make up the outer portion of the ingot. The resultant rough cylindrical forging is much less sensitive to subsequent handling.

The rounded-up ingot is reheated and forged in successive steps to finished size. The required number of operations varies with the dimensions of the piece and the composition of the steel. Care must be taken that the mass is heated and cooled slowly and uniformly at all times, that all forging work is done in the proper temperature range, and that all portions of the shaft heated to forging temperature receive some forging work before being cooled again. If any surface defects appear, the forging is immediately returned to the furnace and annealed. After it is cool, the defect is removed by chipping or grinding, and the steel is reheated. Often the number of reheatings runs to as many as 20 on forgings of this type.

Large work is usually done between a single flat top die and bottom V-dies (or two dies at an angle). If the shaft contains portions of different diameters, the reduction is started with a V-tool, which is made in the form of a half-wedge. This cannot be used to any great depth, and the smaller portion is usually set down beneath the flat dies of the press.

Upset and Hollow Forgings

The method of forging just described works the metal longitudinally, and therefore results in considerable improvement in longitudinal properties, but sometimes the major stresses in a forging are tangential or radial. It is then well to work the metal in this direction, and usually this can best be done by upsetting the forging beneath the press. Depending upon the dimensions of the piece, this may be done in several ways. The simplest is to upset the entire rounded-up ingot. Sometimes it is better to form a shaft with a central body of larger diameter than either end, when it is set vertically in the press with one or both of the smaller ends protruding through bolsters. The body only is upset in this operation.

Many present-day forgings are hollow and are so forged; large boiler drums or pressure vessels fall into this category. It is comparatively simple to make hollow cylindrical forms on a mandrel. Consolidation of the central portions of the ingot is then of minor importance. Usually work begins by slicing off the top and bottom scrap under the press. A longitudinal hole is then bored in the remaining portion, or the hot ingot may be set up vertically and cored beneath the press. In either case, the weak central portion of the ingot is removed.

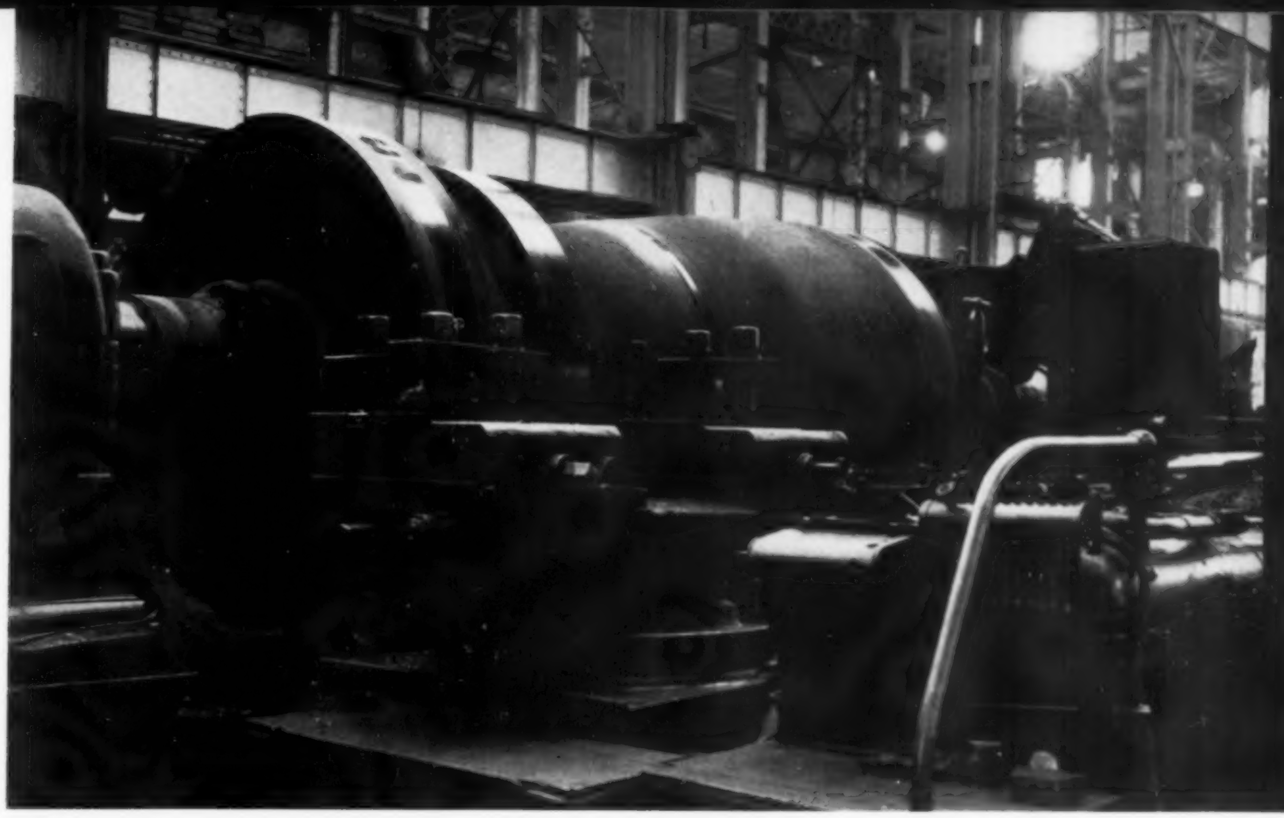
The cylinder is then formed on mandrels which are strong bars of proper diameter extending through the central hole. Increasing the diameter of the cylinder is termed "expanding", and is done on a long mandrel supported on both ends. The only portion of the metal worked while "expanding" is that between the mandrel (which now acts as an anvil) and the upper die of the press. This upper die is shaped to increase the diameter of the forging with comparatively little increase in length.

"Drawing" the cylinder refers to its elongation, and is usually done on a mandrel almost as large as the inner diameter and unsupported at its ends. The metal may thus be worked at three spots — between a flat top die and the mandrel and between the mandrel and the inclined surfaces of a bottom V-die. Such dies are shaped to favor elongation with little increase in diameter.

The "drawing" or elongating of such cylinders usually begins at mid-length and leaves heavier sections at the ends. If it is desired to neck-down or close-in these ends, the cylinder is cooled and these heavier sections are machined so that when closed-in they will be of correct thickness and of even contour. The heavier end sections also may contain mechanical folds or even tears which might develop into serious defects if they were not removed before final closure. (It is often advisable to machine the bores of cylinder forgings before the ends are necked down.) The actual operation of necking down the ends may or may not be done on a mandrel; flat dies are generally used for this operation, although the bottom one may be a V-die. The entire forging is then heat treated.

Heat Treatment of Heavy Forgings

All large forgings must be heat treated in some way. Temperatures at which mechanical work must be stopped on large masses are usually necessarily higher than those for smaller parts. Possibilities of non-uniformity in internal structure are greater. The very least that



Steam Turbine Rotor Forged of Alloy Steel. Largest diameter 70¼ in.; over-all length 21 ft., 7⅞ in.

can be done is to anneal the forging to relieve and equalize internal strains.

While the underlying principles of heat treatment are no different from those for small masses, the practice on large forgings is found to involve a number of complications.

In planning the details, it must be realized that one of the heat treater's most useful aids can be applied to large masses only with the greatest care. This is the liquid quench. Liquid quenching of large masses, being difficult to apply effectively, may promote non-uniformity of physical properties and dangerous distribution of stresses. It tends to benefit only the outer zones. These facts are now generally conceded, but it was not so long ago that the forging manufacturer had constantly to resist demands to liquid quench extremely large forgings.

There are exceptions to every rule. One well-known type of large forging, hardened rolls, must be liquid quenched to obtain the hardness desired. Gun tubes and armor plate of great total weight, but of relatively light, uniform section, are advantageously quenched to obtain high physical properties, or high surface hardness. On the other hand, it is recognized good practice to avoid liquid quenching of shafts of large diameter which are subject to high rotative stresses or of any highly stressed parts of large cross-section.

The primary objects of the heat treatment of large forgings should be the production of a piece free from internal strains and with the best possible grain refinement. Higher physical properties, if needed, may be obtained by the addition of alloying elements. In this connection, it may be noted that practically all of the S.A.E. steels, as well as other special analyses, have been used for the manufacture of large forgings.

The heat treatment usually begins by heating sufficiently high above the critical range long enough to effect a complete solution of the micro-constituents. Extreme care must be taken in this first heat, just as extreme care must be taken in the first forging operation. The majority of the strains left by the forging operation are relieved in this first heat.

The piece should be charged into a heated furnace before it becomes cool from forging. It must be heated up to temperature very slowly and uniformly. It must be held at temperature a long time. The old rule of "an hour per inch of diameter" is a good one, even though the diameters are extremely large. Cooling from this first heat may take place preferably in the furnace or, on occasion, in the air.

For grain refinement repeat this heat treatment either once or a number of times at successively lower temperatures, each above the critical range. These heats are all performed slowly and carefully. In each case the forging is held at temperature approximately an hour per inch of cross-section, and the cooling is usually in air. Finally, heat below the critical range and cool slowly and carefully.

The practice just described is satisfactory

for carbon steel forgings. Some alloy steels are, however, more subject to internal thermal cracks than the carbon steels. This type of defect may occur during cooling after forging. Experience indicates that great care is necessary during the cooling of a forging for the first time from its final forging temperature. Large alloy steel forgings are therefore charged hot in heated furnaces, soaked out thoroughly at temperatures above their critical range and cooled very slowly and uniformly in the furnaces or in lime pits to less than 400° F. On subsequent heats they may be cooled in air without danger.

Large masses of metal, particularly of alloy steels, are forged with a considerable surplus of metal on the surfaces, which is later to be removed by machining. This surplus is disproportionately larger in large alloy steel forgings than in smaller ones. In the interest of the ultimate stability of the machined forging, it may be advisable to divide the heat treatment operations in order to remove a portion of the excess metal. The subsequent heat treatment serves to relieve any strains set up by the rough machining operation.

Visual Examination Most Informative

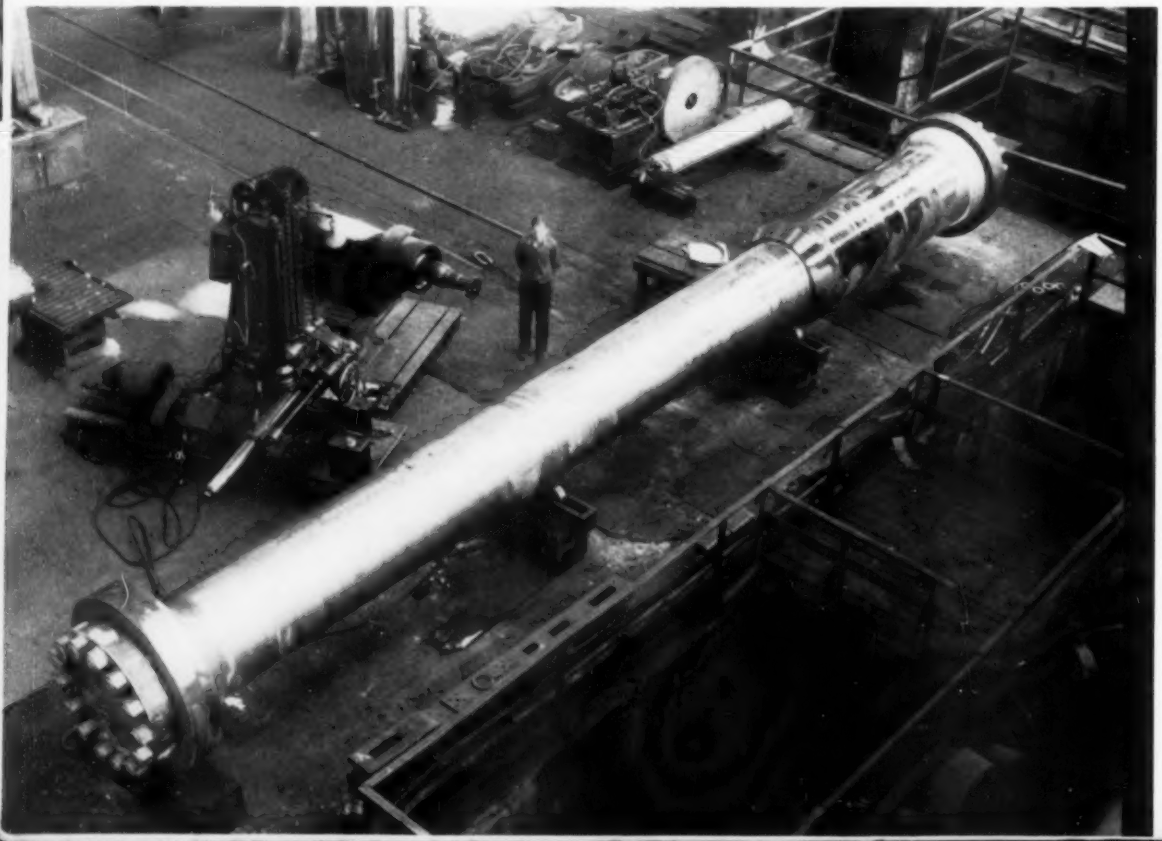
The important thing about tests is to know when and how to take them.

The simplest test for forgings (and for almost all objects) is to look them over thoroughly and carefully. It is very easy, with the present all-too-numerous methods of testing, to forget this most obvious and in many ways most informative test of all. But we must know what to look for. Of course, we can usually see such evident defects as cracks. It is also possible to see surface seams or laps, which, if deep enough, remain after the forging has been machined. Such defects can be removed by chipping, grinding, or machining if they are not too deep. If they do extend into the finished forging, they become problems. Sometimes they are serious enough to cause rejection; at other times changes can be made in the design of the finished forging, or repairs may be made which will enable the piece to be used.

The best known aid to visual examination is the periscope for the inspection of bores. It is of the utmost importance that the bores of shafts or rotors which rotate at high speeds be free from transverse fissures, shrinkage cavities, sharp or deep tool marks or shoulders left from machining. Since the bore is run through that portion of a forging including the central longitudinal axis of the ingot, and the point furthest removed from the beneficial effects of mechanical hot working, it is also the portion most likely to show most evidence of segregation, non-metallic inclusions, and coarse crystalline structure. In alloy steels this tendency is accentuated. Small or isolated inclusions found in such bores are not indicative of poor metal or of a bad forging; they usually represent a local condition natural enough to the size, shape, and analysis of the piece. A decision as to the seriousness of such occurrences should rest with someone familiar with both the intended use of the forging, and also with the characteristics of the steel that has been used.

Various aids to visual examination of external surfaces are used. When conditions justify it, important portions of rough machined forgings are finish machined for better inspection. Macro-etching, sulphur printing, and magnetic testing with iron powder are all useful in making visual examination more effective.

Seldom, if ever, is the common tensile test omitted on an important forging. From this



Hollow Forged Alloy Steel Reaction Cylinder 36¼ in. Diameter and 40 Ft. 9 In. Long. Able to Withstand Test Pressure of 5250 Psi.

test a number of things can be learned. First, of course, it indicates whether or not the one who is to use the forging will be satisfied that his purchase meets his specifications. Coupled with a knowledge of the chemical analysis, the test results verify the efficacy of the forging work and the subsequent heat treatment; in fact, the experienced observer can, from tensile test results and a visual examination of the test-bar ends, go so far as to predict the results of many other physical tests that may be made on the forging.

Location of Test Pieces

The number and location of the test bars should be carefully considered. Too many or poorly placed tests can add much to the cost of a forging without any compensating benefits. In fact, poorly placed test bars may even prevent the forger from making his forging to its best advantage. While it is impossible to formulate general rules, representative test bars should be taken at locations which represent the condition of the metal to be tested, but which do not necessitate undesirable methods of forging the piece.

All of the tests used on small forgings are applied on occasion to their larger brothers. Bend tests often accompany tension tests and furnish some indication of the toughness of the material. Impact tests have not been required on large forgings in the United States to the extent noted in European practice. Some idea of the results to be obtained from both of these tests may often be gathered from the tensile tests. Micro-examination is frequent; it supplements the results of the tensile test and confirms the effects of heat treatment. Pressure vessels are tested hydrostatically at pressures higher than those they will resist in service. Turbine rotors are tested for stability at elevated temperatures by heating them while turning in a lathe. A distinct element of reality is introduced in the ballistic test of ordnance; shells are tested against armor, and vice versa, simulating actual conditions.

In all of these tests, there is evidenced the desire of the engineer for assurance that he is obtaining a forging which will answer his needs. In this desire, engineer and manufacturer unite. The manufacturer has a genuine interest in proper testing, for it is equally important for both him and his customer to have the information to be gained thereby.

PLASTIC MATERIALS FOR AIRCRAFT

From Editorial in The Engineer, *Jan. 20, 1939*

SOME two years ago Dr. de Bruyne, of Cambridge, communicated to a meeting of the Royal Aeronautical Society the results of his efforts to produce a plastic material, of the reinforced synthetic resin type, which would be suitable for aircraft construction. The material then described had a ratio of tensile strength to density almost equal to that of duralumin. Although much work has certainly been done both here and abroad to find a plastic which will not merely equal duralumin, but will markedly improve upon it, little has so far been allowed to be published. Dr. de Bruyne has, however, lately given an account of the position reached after two years' further work. He found it better to use linen threads instead of cotton as his reinforcing material, with an improvement in the ratio of tensile strength to density of not less than 60%, so easily beating both duralumin and high grade steel.

This is a striking result. Instinctively one thinks of mechanical presses producing wings and large fuselage parts in considerable numbers, but although this may indeed happen, the producer of this material not unnaturally suggests a less ambitious and less costly start by building what may be termed "planks"—apparently of any desired length—which can be cut up or shaped to form wing spars or any other structural member. These planks are produced in a machine which draws the loose fibers into a uniform band which then enters an impregnating bath and is subsequently dried and compressed. The claim made for the material so produced is that it can be easily built up into structures capable of withstanding heavy loads and has an unusual strength-to-weight characteristic. It is, of course, free from any corrosion trouble. It is not, however, a material which lends itself to riveting or bolting, or even to gluing, so that a new technique for fastenings and joints has had to be designed.

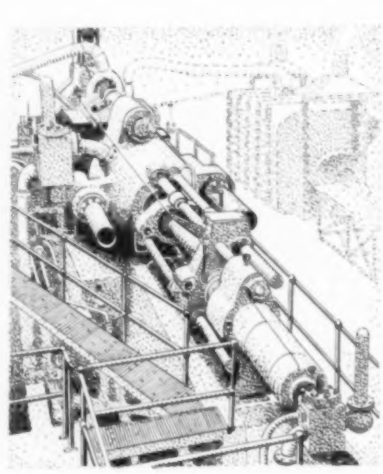
Let it be admitted that the ratio of tensile strength to density, important though it may be, is not everything. Consideration must also be given to strength in shear and the elasticity of the material. Moreover, even when this has been done, the designer must be prepared for such changes in structural form as will suit the special aptitudes of this—as of any other—new material. Forms suited to such intensive work as the multitudinous riveting now so common can hardly be expected to prove the most suitable for a similar type, in which individual joints may be almost as rare as now they are common.

CRITICAL POINTS — A WEEK'S DIARY

TO NEW YORK to the 150th meeting of the American Institute of Mining and Metallurgical engineers (to which title the letters "Inc." are properly now attached). The senior organization has become so diverse in its interests through a multiplicity of divisions that 51 sessions were crowded into four days, at which no less than 261 papers and topics were listed for discussion. The handy appellation "Mining Engineers" is quite obviously no longer applicable to such a group — even the added "Inc." seems rather futile.

The Mining Engineers Consider Pure Metal

Among this abundance of intellectual fare were fortunately found several solid entrees of metallurgical interest, such as day-long sessions on high purity metals, surface quality of stainless steels, or "What makes them pit?" and experimental methods in the study of steel making, which reminded one of a session of the Openhearth Committee, albeit of a scientific air where details of experimental technique were discussed. As to the first topic, some data were secured supplementing the editorial in METAL PROGRESS for January of 1938, and again emphasizing the generalization that purest metals are coarse grained, tender to work, and of low recrystallization temperature, and their use depends on astute alloying which improves their mechanical properties without spoiling their physical and chemical ones. In the preparation and experimentation much uncertainty exists about the determination of minute impurities — especially gaseous elements — and the adaptation of conventional laboratory tests, which are suitable for strong, fine-grained metals, to pure, weak, coarse-grained ones.



Everyone commented on the circumstance that Prof. DANIEL HANSON of University of Birmingham, England, the visiting lecturer for the Institute of Metals, chose "The Creep of Metals" for his subject, while quite independently, H. W. GILLETT, Howe Memorial Lecturer, decided to talk on "Some Things We Don't Know About the Creep of Metals". Actually, *both* lecturers emphasized the fact that we have a relatively small amount of exact knowledge, and both warned against the tendency to make unwarranted assumptions.

Creep of Metals

Professor HANSON attempted to analyze the meaning of a typical time-elongation curve which measures the creep of a metal under steady load at elevated temperature. This curve he divided into four parts, *(a)* elastic stretch that occurs almost instantly, *(b)* the succeeding plastic flow that rapidly settles down to a low figure, a portion of the curve he believes of utmost theoretical and technical importance, *(c)* the time, longer or shorter, that the extension is at this very low but steady rate, and *(d)* approach to fracture, when the rate of stretch is steadily increasing. Since portions *(b)* and *(c)* are commonly held to be due to automatic strengthening during extension under load, the unexplained anomaly exists that the same stress that strengthens the metal will ultimately break it. After examining five possible mechanisms for this action, HANSON seemed inclined to the hypothesis of "thermal flow" — the translation of atoms, one by one, to new and less resistant positions, caused by superposing mechanical stress on the constant thermal vibrations, a gradual action eventually damaging the metal and supposed to occur more easily at the disorganized latticework in grain boundaries.

Doctor GILLETT's discourse about creep of metals was more a summary of experimental knowledge about commercial steels. He pointed out that killed steels perform much better in the creep test than rimmed steels do, and the reason for this is one of the many things about creep we are ignorant of. Even though Professor HANSON said there was no such thing as a "limiting creep stress", Dr. GILLETT told of one sample of 0.35% carbon steel having been under test for 20,000 hr. and still stretched uniformly. Steel, therefore, *can* be very stable at high temperature. While coarse-grained steels tested in America have been much stiffer at high temperatures than fine-grained ones, HANSON believes that there is danger in metal that is too coarse. As to composition and constitution, the carbon should apparently be kept in a medium range, alloyed with molybdenum or tungsten, and the microstructure lamellar pearlite rather than sorbite (finely dispersed carbides). Users of high pressure, high temperature equipment should remember that elevated temperatures increase the tendency for the micro constituents in steel to move toward structural equilibrium — that is, for the carbides to agglomerate in rounded particles, and this spheroidized structure has the least ability to resist creep. Perhaps the ultimate steel for high temperature strength will be one properly alloyed and heat treated so it contains in supersaturated solution a substance that at operating temperature will very slowly precipitate a cloud of submicroscopic particles throughout the grains, thus continually strengthening them. In other words, the metallurgist may be able to utilize the almost universal phenomenon of precipitation hardening, adjusting the composition of the metal for the proper strengthening rate at the proper temperature, without developing undue brittleness under shock.

Resistant Steels

If it is permissible to interpolate here something that is not part of this week's diary, it may be written that this noticeable emphasis by the Mining Engineers on the more scientific aspects of metallurgy is reflected by some lectures at Case School of Applied Science, planned by the Cleveland members and appealing to that group of younger men who do not tremble at the words "physical metallurgy" and "thermodynamics". KENT VAN HORN, metallurgist for Aluminum Co. of America, discussed internal stresses in metals — where they come from, how they may be measured, their effect on articles in service, and how the dangerous stresses may be relieved. The mechanism of stress relief (or "stress relieval", as VAN HORN prefers to call it with a more lilting word of new coinage) is quite obscure, starting as it does at moderate reheatings, considerably below tempering, and the threshold of recrystallization. This listener imagined a rough relationship with creep at those temperatures where stress relieval occurs with some rapidity. Certain regions in the metal may then find themselves stressed above the then yield point, lowered by the heat, and a minor internal reorganization by plastic flow will relieve the stress at those localities. This imagined mechanism has the disadvantage that it attempts to explain an action at microscopic regions by another action measured as a statistical result on comparatively huge masses. On the other hand, the self-same fact logically precludes the objection that no creep has ever been measured at temperatures as low as stress relieval is known to occur.

Control and Utilization of Internal Stress

The audience was enriched by the presence of GEORGE SACHS, expatriated German metallurgist (now a faculty member at Case). He dug up much of our present knowledge of internal stress, and is of the opinion that it is now just about sufficient for practical use. In other words, we should not only be able to avoid damage from internal stresses in machine parts, but actually put our knowledge about it to work for their improvement. For instance: Failure by alternating stress (fatigue) is greatly accelerated in corrosive surroundings if the nature of the alternating stress puts tension on the surface. On the other hand, corrosion is innocuous if they are merely fluctuating compressive loads. It is almost as though the corrosion penetrates into regions where the atoms are stretched apart slightly — into something like tiny cracks — whereas the attacking substances are repelled when the metal atoms are always squeezed together somewhat. However that may be, the practical aspect is this: If a stress-relieved axle or propeller is finally burnished by pressure rollers, a thin surface layer is put in a condition of strong compression, so great in intensity that

Improvement of Axles & Propellers

the bending loads of service never stress the pre-stressed surface beyond zero to tension, and life and resistance to fatigue in atmospheric and oil corrosion are greatly enhanced.

When building machinery, most metallurgical problems are problems in mechanical engineering and design. Similarly, it is not surprising that metallurgists in the petroleum and chemical industries are principally worried with corrosion. BYRON MORTON, petroleum engineer in International Nickel's staff, told me that the biggest metallurgical problems in the oil fields involve well casings (where great tonnages of tubing are required with high yield in compression and good corrosion resistance), drill pipe of higher strength and endurance, and sucker rods immune to pit corrosion and its associated damage to endurance.

Corrosion, Principal Refinery Problem

This same importance of corrosion was emphasized by ROY MOORE, during an inspection of Socony-Vacuum Technical Service Laboratories at Greenpoint, Brooklyn, where he is metallurgist. Here gasoline seems to be taken more or less for granted; more space is devoted to petroleum byproducts such as paraffin, insecticides, lubricating oils and greases, roll oils, quenching oils, cutting oils, asphalts for roads and roofs. MOORE was of the opinion that vigorous discussion of interesting and perplexing changes found in the microstructure of still tubes withdrawn from service has caused an unwarranted worry over the adequacy of present-day metals. Of course, such discussions are of value to the steel maker, helping him interpret his product in terms of customers' needs, but in reality, refinery troubles due to metal are very rare. Some failures are caused by operating errors, accidents, abuses or drastic conditions imposed on the metal beyond the designer's control. Corrosion and oxidation and stress at high temperatures are certainly to be guarded against continually, but for nearly all refinery conditions a suitable commercial alloy can be found. Refinery equipment of plain carbon steel or carbon-molybdenum steel is handling most of the crude petroleum year in and year out; for corrosive crudes from certain fields the refiner goes first to 5% Cr-Mo steel, then 9% Cr steel, and finally to 18 Cr, 8 Ni stainless. New catalytic processes for cracking the heavy fractions and polymerizing the gases will probably not increase the severity of service, now at about 700° F. and 1000 psi.

On the other hand, condenser tubes give the refinery man a good deal of trouble when the cooling water is briney and the crude is corrosive. Each case is a problem in itself, and sometimes ferrous and non-ferrous alloys within the price range for the job have not been suitable. Admiralty brass is used in most condensers, but combinations of free chlorides, ammonia and H_2S will ruin it in short order; recourse may then be had to various silicon bronzes, aluminum brasses, 70-30 copper-nickel, and even duplex metals wherein the inner lining resists the vapors and the outer shell resists the brackish water.

Toward the week-end to Wilmington, and a very pleasant day with HAROLD MAXWELL, chief metallurgist in Du Pont's engineering department. He is not nearly so easy about available metals, for the chemical manufacturers are approaching the practical limit of commercial metals in some difficult operations; temperatures and pressures existing in a petroleum still would be merely the beginning in the converters and reaction chambers used in the synthesis of ammonia and the hydrogenation of coal. Practical limits are now on the order of 1000° F. and 1000 atmospheres (15,000 psi. pressure). Under these conditions hydrogen actively reacts with carbides in steel and oxides in copper; recourse may be had to silicon bronze, carbon steel stabilized by tungsten, and low carbon, single phase, chromium-nickel alloys. In these most critical cases equipment would be lined with metal having the highest resistance to gas penetration and chemical attack; the thick-walled outer shell to take the pressure would be a ductile steel of high creep resistance. Such items of equipment are kept under close observation and replaced frequently.

Wanted: A Super-Steel

Aside from these more spectacular activities, the routine cares of a metallurgist in the chemical industry are again concerned with corrosion. He must accumulate information as to the best metal to resist corrosion of the thousand and one service conditions, including their resistance to fatigue and creep, and to advise on problems of new construction or replacement after failure. Sometimes the most highly resistant metals are desirable to prevent contamination of the product rather than to prevent damage to the equipment.

PIT CORROSION OF STAINLESS STEEL

From Progress Reports to The Chemical Foundation

By H. H. Uhlig and John Wulff

ABOUT FIVE YEARS AGO stainless steel tanks and fire lines were installed in some American naval vessels, and rapid failure by pit corrosion ensued. The corroding solution was stagnant sea water, or more or less polluted harbor water, incapable of damaging the metal by general corrosion. Since many ship parts of stainless steel in contact with moving or aerated sea water were behaving excellently, the first guess was that the trouble was due to lack of enough oxygen in the solution to correct any damage done to the impervious oxide layer which is supposedly responsible for 18-8's corrosion resistance. A brief discussion of these matters was given in METAL PROGRESS for February 1935.

Shortly thereafter The Chemical Foundation, which owned several patents on high chromium-iron alloys, financed an extended investigation of pit corrosion at Massachusetts Institute of Technology. This work has continued ever since, under the supervision of C. L. Norton, director of the Division of Industrial Cooperation. Six formal progress reports have been made by the principal investigators H. H. Uhlig and John Wulff, and are now released for review by William W. Buffum, treasurer of The Chemical Foundation. A notable paper on the nature of passivity presented to the last meeting of the A.I.M.E. by the same men is an elaboration of one of the reports.

After a reproducible and handy method for causing pit corrosion had been developed (as described by Howard A. Smith in METAL PROGRESS, June 1938), most of the study was focused on conditions at the very surface — within a few atom layers on either side of the metal-fluid interface. In general, the metal was appraised by counting the number of pits and measuring their depth, and weighing the loss after a spot on the surface had been subjected to circulating acidified ferric chloride solution for 4 hr.

Such a test quickly checked the commonly held belief that a surface was greatly improved (almost to complete resistance to pitting) by buffing and polishing. Electron diffraction patterns showed that such a surface was highly disturbed and of no evident crystallinity for 30 or more atom layers. (Similarly the oxide film, if any, is probably less than 7 A in thickness, and more the nature of adsorbed oxygen rather than a thin layer of metallic oxides — physical attachment rather than chemical.) Curiously enough, this almost non-crystalline polished surface is the best that can be produced in 18-8 stainless steel (by that meaning 18 to 20% Cr, 8 to 10% Ni, and 0.10% or less carbon) except by long vacuum annealing at 1900° F., which causes very large grains to grow. In such annealing all gas is liberated from the metal, there is a slight vaporization of metal from the surface, and small roll marks and scratches are obliterated. No pitting could be induced in the standard drop test on such metal in 122 hr. The good effect is also more than skin deep, for if the surface is ground and polished, it is again immune, even after the disturbed film due to polishing is etched off.

However, such vacuum annealed metal will pit readily if the surface is coarse ground, and Professor Wulff believes this to be of great importance, for he supposes that such a surface is full of invisible flaws and a flaw is the physical discontinuity which locates a pit. This hypothesis agrees with the experimental fact that light cold work, as a skin pass in cold rolling, smooths the surface and increases the resistance to pitting, but heavy cold work (on the order of 50% reduction and greater) accelerates pitting markedly, presumably by ruptures in the planished surface. Ordinary annealing to relieve the internal stresses in the

cold-rolled strips did not change these results.

Free-machining stainless, high in sulphur and selenium, and other samples containing many non-metallic inclusions, pit far more readily than cleaner steels. Inclusions identifiable as nickel oxide, chromium oxide, and sulphides induce a pit to start alongside almost immediately; iron oxide and silicate inclusions are not nearly as active in this regard. This evidence is interpreted to mean that there are small cracks at and near these inclusions, especially after cold rolling, and these supposed physical discontinuities are held to be more damaging than visible chemical segregations. He also cites one sample, entirely free of slag particles under examination at 2000 diameters, that pitted readily.

Much careful work was done on the problem of whether carbide or ferrite will induce pitting. Carbides were eliminated as a potent cause by the discovery that incipient pits were preferentially located at austenitic grain boundaries rather than at identifiable particles of carbide within the grains, and further that several alloys containing less than 0.01% carbon vary in pit susceptibility with degree of cold work in a way quite parallel to experiments on commercial 18-8 containing up to 0.10% carbon.

Since cold work is supposed to transform austenite to ferrite at the same time it is precipitating carbide, it was next thought that the two-phase structure of austenite and ferrite might form the electrolytic cell instigating a pit. The amount of ferrite in a sample may be estimated by its magnetic properties and by electron diffraction, and its location on the surface can be determined by colloidal suspensions of magnetic iron oxide; the colloidal particles gather over magnetic areas at and near the surface. Since no connection could be discovered between location of pits and ferrite areas, nor a parallel between pitting susceptibility and amount of ferrite present, it was concluded that ferrite (austenite transformed by heat or cold work) is not the prime cause of pitting. This conclusion does not invalidate the common assumption that ferrite precipitated at grain boundaries and depleted in chromium is the cause of intergranular corrosion.

The remarkable immunity of vacuum-annealed samples led to some studies on chromium-nickel alloys made from metals of electrolytic purity, melted and cast either in a vacuum or under hydrogen or nitrogen. Carbon in all these was below 0.01%. Strangely enough all these melts were magnetic, two-phase alloys containing about half austenite, half ferrite, except those melted under nitrogen and containing 0.15 to 0.30% N_2; these were austenitic and non-magnetic. Aside from the theoretical interest in these alloys (something must be radically wrong with published structural diagrams of the iron-chromium-nickel system), the fact is that all the ingots pitted readily. Forging, annealing and quenching improved the performance of all, but only the single phase alloys containing nitrogen were free from pitting. In all alloys the corrosion resistance was lowered after heating at 1100° C., that is, within the range inducing susceptibility to intergranular corrosion, even though the alloys have almost no carbon. Professor Wulff concludes that the initiation of pitting is therefore not due to nitrides, oxides, hydrides or carbides. About the only things these experiments do not eliminate are surface flaws, concentration gradients, and duplex (two-phase) microstructure.

Manufacturing Precautions Needed

Any practical application of these tests comes from their indication of the great importance of cleanliness in the alloy and its surface finish. Best results are had if the smooth surfaces are pickled, polished and passivated by dipping in nitric acid — a conclusion verified by studies on the influence of mechanical finishing on corrosion characteristics made by H. A. Smith and S. P. Odar of Republic Steel Corp. and reported to the A.I.M.E. convention. While the evidence that minor surface defects are the cause of pitting in plain 18-8 is plausible, it could not anticipate nor predict the discovery that 2 to 4% molybdenum will prevent pitting, even on surfaces receiving no special preparation. For instance, an 18-12 with 3% Mo will not pit under acidulated 10% $FeCl_3$ in six months. For grading such alloys 20-hr. exposure to an acidulated 30% solution is necessary.

It now remains to indicate very briefly the experimentation, principally by H. H. Uhlig, which has led to the conclusion that pits are caused by ferric chloride attack concentrated at some point where the passive stainless steel surface is for some reason converted to an active surface, and that the passive surface has to do with the distribution of electrons among the metallic atoms rather than the creation of an impervious oxide layer. *(Cont. on page 298)*

IMPROVEMENTS IN THE ART OF CASTING ALUMINUM ALLOYS

By H. J. Rowe
Foundry Division
Aluminum Co. of America
Cleveland, Ohio

THAT the economical production of aluminum has been the result of scientific research is well known. The same research in a short span of less than 50 years has also played an important part in the development of fabrication methods to a point comparable with those for iron and copper, arts whose origins date centuries before.

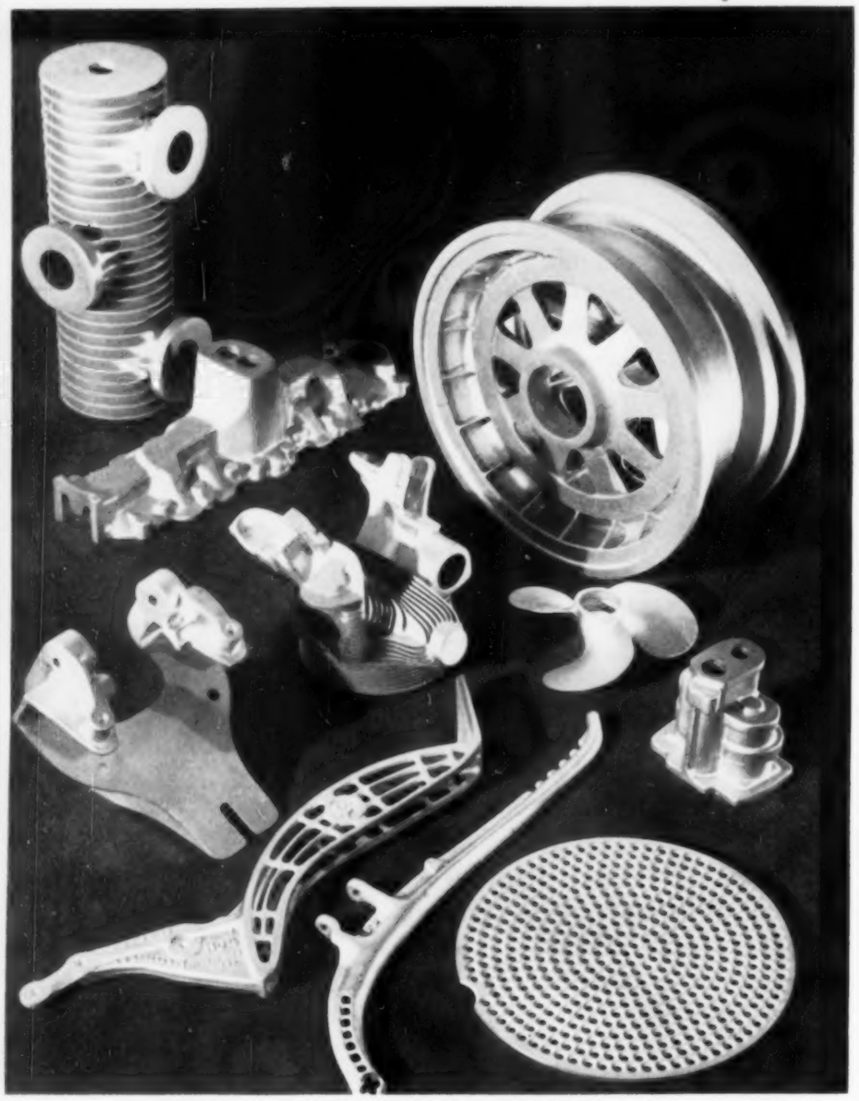
The art of casting aluminum is divided into three rather distinct processes. Because of its universal adaptability, the *sand casting* process is the best known and most frequently used, and it differs in no essential way from the sand process used for the other non-ferrous metals. Aluminum alloys do possess, however, specific characteristics which dictate certain specialized metal-handling and molding practices. Sand molds are used for small quantity production, for castings requiring intricate coring, and for large castings.

Permanent mold process, with its metallurgical superiority, is of next importance from the production standpoint. Metal molds and cores are used, the aluminum being fed into the mold cavity by gravity. The chill imposed by metal molds refines the grain and reduces porosity, both of which make for a substantial improvement in the strength over similar sand-cast parts. A variation known as the *semi-permanent mold* process employs dry sand cores in place of metal cores, and greatly enlarges the number of applications by overcoming many of the restrictions imposed by metal cores.

The third casting process of importance is the *die casting* process, known particularly for accuracy of reproduction. As with permanent mold, a metal mold (or die) and metal cores are used; molten metal, however, instead of being poured into the mold, is forced into it under high pressure. Operating methods differ in few essentials from the die casting processes used with other metals. Die and core design, as well as the nature of the process itself, control and limit the type of castings that can be satisfactorily produced, but numerous parts are produced very economically—particularly those on which a minimum of machining is desired.

Each of these casting processes has seen significant improvement during the last few years which has greatly expanded their fields of use. A better understanding of metal characteristics, metal handling processes, and mold and die designs has improved the soundness of castings. Improved die materials have enabled the size of the castings to be increased. New alloys with improved casting characteristics have been developed for larger and more intricate castings. Sand castings weighing 500 lb. are therefore quite common; castings up to

Paper read before the 1938 Western Metal Congress



Universal Adaptability of the Sand Casting Process as Illustrated by Typical Castings

7000 lb. have been satisfactorily poured. Permanent (and semi-permanent) mold parts from a few ounces to 20 lb. in weight are likewise common foundry products, although permanent mold parts weighing up to 50 lb., and semi-permanent mold castings weighing up to 500 lb. have been made. Die casting limitations have also been materially overcome, parts weighing from 16 to 20 lb. now being quite common.

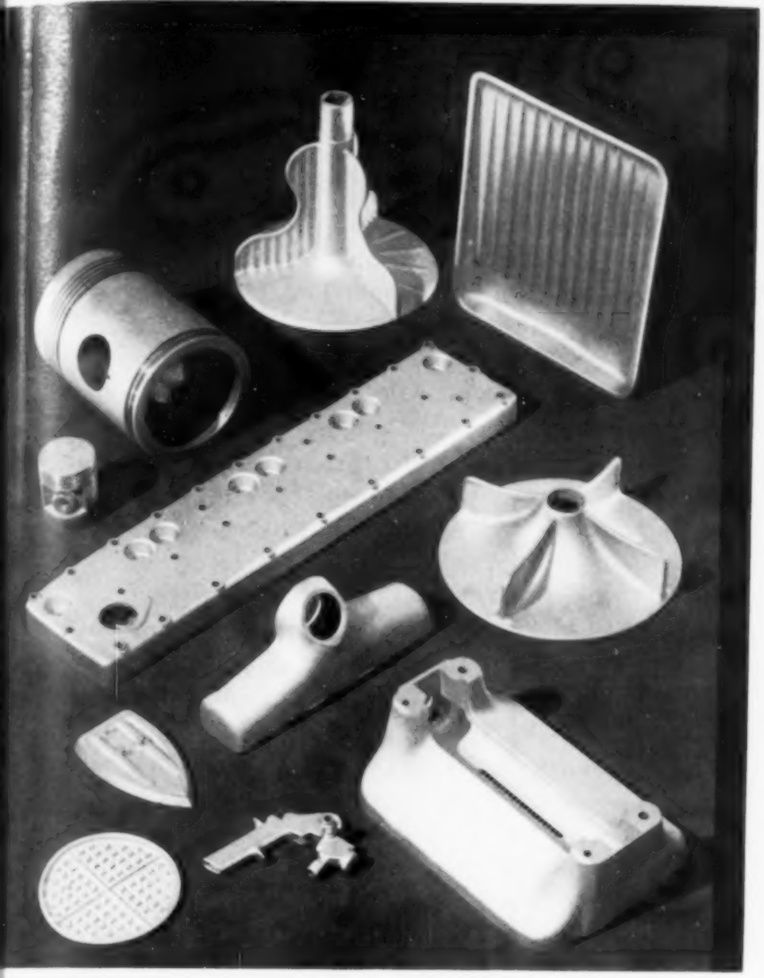
Alloy formulation has been, and still is, an important factor, because commercially pure aluminum possesses neither the mechanical properties nor casting characteristics satisfactory for general use. Aluminum-silicon alloys were early examples of alloys with suitable foundry characteristics. Demand for improved mechanical properties resulted in a 4% copper alloy whose properties could be materially improved by thermal treatment; this was the first alloy from which heat treated castings were produced and is still today the most widely used casting alloy where high strength is required, an outstanding position attained through long and excellent service in various engineering fields.

More recently several new alloys have been added, which warrant mention here. The most important, from the standpoint of their present production, are the heat treated, high strength, aluminum-silicon-magnesium alloys, two of which are in common use — a 5% silicon and a 7% silicon. Both combine the excellent casting characteristics of the early aluminum-silicon alloys and strength approaching that of the heat treated aluminum-copper alloys. As such, they find well defined applications in intricate castings required to be pressure tight, and other parts difficult to cast in older alloys. They resist corrosion comparably with the common 5% silicon alloy. Although their mechanical properties are in some cases slightly lower than those of the older heat treated 4% copper alloy, they are replacing the latter in many applications requiring improved castability and resistance to corrosion.

Several alloys containing magnesium as the principal alloying addition have also come into commercial use recently. They possess a number of desirable characteristics including an exceptionally high resistance to corrosion and surface tarnish. Their mechanical properties are also very good and they machine to a very smooth surface. Of these, one with 4% magnesium is finding considerable application where moderate strength is required. For higher strength a heat treated, 10% magnesium alloy is available; in fact, this alloy has the highest combination of strength, ductility, and impact resistance of any of the aluminum casting alloys in commercial use today. Aluminum-magnesium alloys are somewhat limited (by casting characteristics) as to the type of designs which can be cast satisfactorily.

The limitation placed on the production of many castings by their design has become more fully appreciated with the demand for increased quality and soundness. Normally, designers can achieve their desired result through several different designs and the foundry is always glad to cooperate in the selection of the design best suited to production requirements. Much has been accomplished by the cooperation of designers and foundrymen; still further improvement will be possible.

Extensive study of heat treating practices has resulted in several important improvements. By controlling the method of heating and the selection of quenching medium, the internal stresses which would normally develop in large and intricate castings can be materially reduced.



Castings Made in Permanent and Semi-Permanent Molds Are Characterized by Their Metallurgical Superiority

Study of the effect of various heat treatments on dimensional stability and resistance to corrosion has resulted in several new treatments providing castings with the optimum properties for each application.

Welding has frequently been employed as a method of repairing surface irregularities on the less highly stressed castings. Recently, with further improvements in the welding art, it has been used as a means of fabricating certain structures involving castings. By designing for this type of fabrication and selecting the proper alloy, quite satisfactory results have been obtained. The welding of heat treated castings without subsequent heat treatment is still, however, a questionable practice.

A great variety of finishes is now available for both corrosion protection and appearance. In addition to the older mechanical finishes, electroplated finishes of nickel, copper, zinc, tin and chromium may now be satisfactorily applied to certain of the cast alloys. Chemical finishes, such as "Alrok", provide unusually good protection against corrosion as well as a base for paint. Electrolytic oxide coatings, particularly the so-called "Alumilite", provide a variety of characteristics; in addition to their protective value, they possess remarkable abrasion resistance with good dielectric strength. Certain types are also readily impregnated with dyes and mineral pigments both for color effects and to increase the corrosion resistance.

Competition between castings and other methods of fabrication, and a demand for improved soundness and reliability, has required more exhaustive inspection methods, not only for final inspection but as a means of establishing the most suitable foundry practice.

Much has already been said about the use of X-rays as an inspection tool and it has already accounted for much improvement in cast aluminum parts. X-rays have found their most important application, however, as a tool for establishing the foundry practice and insuring a practice that would provide maximum soundness in those parts most highly stressed. There is still much to be desired in the use of X-rays themselves as an inspection tool or as a means of establishing the mechanical properties of a casting. Too often microscopic imperfections (such as result from improper heat treatment), oxide films, or intergranular shrinkage, affect the casting strength more than any macroscopic condition detectable by X-rays. In these cases the use of a microscope or other test methods is still essential.

Among the various other methods that have been used as a means of controlling casting quality are static, impact, and endurance tests on the entire casting. It must be admitted that such tests, if carried to destruction, will not serve as an inspection method. They do, however, afford an excellent means of checking casting design and foundry practice. In connection with X-ray and microscopic examinations they also serve to establish certain inspection standards for subsequent castings of a similar type that are produced under comparable conditions.

A more direct method of establishing the quality of castings would be to proof-load each one. This has been successfully done in a number of cases but is restricted to parts subject to simple and well defined stresses. For instance, castings loaded as a simple beam may be readily tested if a proof load can be established. Proof loading yields data only in the elastic range and gives no indication of the behavior beyond the yield strength of the material.

In order to obtain the maximum benefit from any of these quality control tests, both the designer and foundryman must know the type of loads which the casting must sustain in serv-

ice, their magnitude and direction. Such information materially helps the foundryman to establish his practice and to provide maximum soundness in the critical, if not in all, sections. This can then be checked by X-rays prior to, as well as periodically during, the production run. When questionable cases arise, the same data will guide tests on the casting as a whole, assuming testing conditions comparable to the service conditions, either to establish satisfaction for the purpose intended or to indicate that better foundry technique or design are required.

It is emphasized that various coordinated investigations into alloy composition, foundry technique, heat treatment, inspection methods and finishing operations have so improved aluminum castings that many new and successful applications have been found in the transportation, electrical, architectural, food, and machine tool industries

Perhaps one of the most important points that has been brought out during the recent development of the aluminum alloy casting art is the fact that, regardless of alloy, casting practice, or inspection methods, the nature of the casting art precludes any possibility of producing parts which are absolutely free of internal discontinuities. This does not mean that castings containing such discontinuities are not serviceable. Any commercial casting — and this refers to castings of other metals as well as aluminum — may contain many inherent variations in soundness to a greater or lesser degree and still adequately perform the service for which it is intended in a reliable and lasting manner.

It is quite necessary to recognize the inherent limitations of the various casting processes. There are services where absolute freedom from internal discontinuities may be essential, and even where designs with large factors of safety are undesirable. In such cases the use of wrought aluminum alloy parts is suggested.

Recent New Applications

Any metal or alloy, and any fabrication method, finds its place in commerce in proportion to its ability to serve certain purposes better and more economically than other materials and processes. Thus, aluminum alloy castings, because they frequently fulfill these conditions better than other materials, find numerous and expanding applications in the various engineering fields, resulting in their more general use for many of the older applications as well as new uses in places where castings were formerly considered impractical. Much of this expansion has been the direct result of improved foundry technique, new alloys, and the various other improvements mentioned previously. Other applications have been the natural result of a more general appreciation of the properties and inherent characteristics of the metal.

By far the greatest application is in the transportation industry where light weight is an important consideration. Savings in operating costs resulting from decreased power consumption and the greater smoothness of operation brought about by lower inertia forces are advantages long recognized by the automotive industry. Crankcases, oil pans, gear cases, transmission cases, manifolds, pistons and cylinder heads of cast aluminum alloys have been used in engine construction, and have improved the operating efficiency as well as lowered the weight per horsepower. Bus and truck chassis and bodies have used rear axle housings, brake parts, body fittings, seat stanchions and hardware of cast aluminum to reduce dead weight.

Many of the developments in aircraft have depended in no small measure on the use of aluminum alloys, and the necessity for light weight and high strength for such construction has in turn stimulated much of the light alloy development. Although many aircraft parts are now being made as aluminum alloy forgings, there are still numerous applications for castings in the less critically stressed assemblies in fuselage construction for fittings and hardware, and in the landing gear for wheel centers, tail forks, and brake equipment. Both air cooled and liquid cooled power plants employ a number of cast parts such as cylinder heads, supercharger cases, nose pieces, crankcases, and water jackets.

The last few years have brought about extensive use of aluminum alloys in railroad and rapid transit equipment where increased speed and lower maintenance and operating costs have been considered. High strength castings have been used for many body fittings, air

brake equipment, seat frames, hardware and lighting fixtures. In the undercarriage bolsters, spring planks, draft gear housings, and some truck fittings, have been of cast aluminum alloys. Diesel and electric power units have been constructed of light alloys with a material increase in their power-weight ratio; frames, bed plates, cylinder heads, exhaust manifolds, blower and gear housings, and pistons are being cast successfully. Magnet frames, frame ends, brush holders, and axle caps for electric traction motors have also been provided as heat treated aluminum alloy castings and have resulted in a material reduction in the unsprung weight of such power units.

Although aluminum was used before 1900 for small architectural applications, it was not until the last few years that its use for this purpose became of major significance. This trend was no doubt influenced to some extent by a desire for a white color but of more significance has been the reduction in erection costs due to light weight, and the elimination of many items of maintenance by the excellent resistance to weathering. The pleasing color effects that can be produced by the various new finishing methods have, of course, contributed. Because of the excellent detail that can be provided, castings have found extensive application for spandrels, mullions, sills, copings, grilles and other decorative items.

The Die Casting Process Insures Maximum Dimensional Accuracy for Intricate and Simple Castings

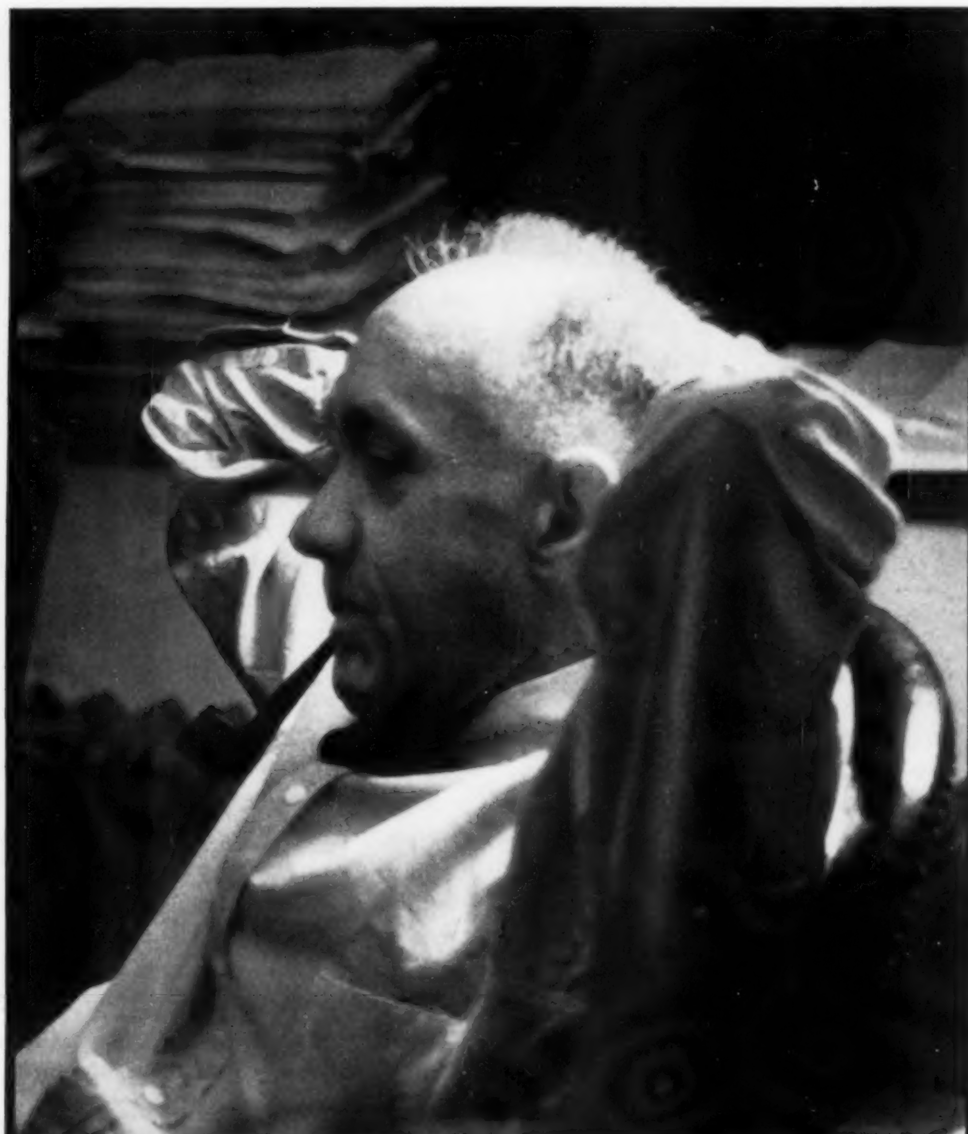
The chemical properties of aluminum are responsible for many applications in the food, chemical, and dying industries. The relative immunity to attack, the fact that aluminum does not accelerate deterioration of certain chemical products, and the non-toxic characteristics in processes for producing yeasts and bacterial acids, are utilized in many applications. The colorless nature of the compounds of aluminum is advantageous in dye work while the non-sparking property is used to advantage in the manufacture and handling of flammable and explosive materials. In the construction of such equipment many castings are used, such as tank fittings, valves, pump housings, fans, agitators, vats, and filter press plates. The dairy industry finds castings very desirable for heat interchanger plates in pasteurizing equipment, butter churns, agitators for ice cream freezers, pipe fittings, and sanitary valves. In the preparation of other food products, castings for tank and digester fittings, molds, freezer plates, and household cooking utensils are common.

The importance of light weight in the design of power shovel and crane equipment for handling material and the ultimate reduction in handling costs resulting from such design has been more fully appreciated during the last few years. In power shovel design, the use of aluminum has permitted as much as a 50% increase in the capacity of buckets and appreciable increase in flexibility of shovel range, without increase in the motive power.

Machine tool builders have found light alloys to be valuable when light reciprocating parts permit higher speeds and reduce vibration, with no sacrifice in the dimensional accuracy that can be maintained. Shaper rams and tool holders, planer tables, and other parts of the reciprocating drive mechanisms are using heat treated aluminum alloy castings; for the drilling head of large radial drills they have reduced undesirable deflection in the radial arm. Accessories which must be frequently handled when setting up a machine are often of

(Continued on page 290)

A SENIOR AMERICAN METALLURGIST



Horace Wadsworth Gillett

CHIEF TECHNICAL ADVISER, BATTELLE MEMORIAL INSTITUTE

DOCTOR GILLETT'S outstanding personal characteristics are his sincerity, complete absence of pose, and love of truth. No matter how unpopular the truth may be, he is ready "to stand up on his hind legs", as he would say, and fight for it, outspoken and racy in speech. As hard-boiled as he prides himself on being, he has the research man's unfailing optimism, unworldliness, and lack of cynicism.

Metallurgy is to him an Alma Mater and he enters into it with as much school spirit as any eager collegian. To this day when he gets an idea he won't wait, but will skip up two or three flights of stairs and perch himself on the windowsill in the room of the man handling the problem to talk it over. It is perhaps this Quixotic quality along with an implicit loyalty which endears him most to his friends. One writes:

"Gil has a passion for practical tests, such as a disastrous test of the life of bearing metals by running his old Dodge up University Avenue hill in Ithaca with no oil in the crankcase, or tests for color sense among fish by substituting the family's gold fish for minnows in fishing for pike in Cayuga Lake. A never-to-be-forgotten picture, directly after a disastrous fire in the Chemistry Building at Cornell, is that of Gil in the flooded basement, with loose bricks for stepping stones and foot rest, getting out the drawings of the rocking furnace to be."

Born in Steuben County, N. Y., he attended Cornell University, getting an A.B. in chemistry in 1906. He remained there teaching physical and electrochemistry until 1910 when he received a Ph.D. He made good use of his summer vacations by working for Thomas A. Edison and A. D. Little. From 1910 to 1912 he was manager of the Aluminum Castings Co. in Detroit. From 1912 to 1924 he was chief alloy chemist of the U. S. Bureau of Mines in charge of the field station at Ithaca. In 1924 he succeeded George K. Burgess as chief of the Division of Metallurgy, National Bureau of Standards. During these years his reputation grew rapidly and by 1929 he was acknowledged one of the nation's outstanding metallurgists. In that year he became director of the newly formed Battelle Memorial Institute in Columbus, Ohio, and also accepted the responsibilities of editorial director of *Metals and Alloys*, the monthly metallurgical magazine then just getting started. Establishing Battelle Institute, nursing it through the depression years, carrying a heavy load of research work, and turning out a large quota of metallurgical research papers and other writings was an enormous labor. This taxed even his unusual stamina and ability, but he came through successfully and in 1934 turned over the directorship of the greatly enlarged Battelle Institute into the capable hands of Clyde E. Williams, and assumed the position of chief technical adviser. His most recent honor is that of giving the Henry Marion Howe Memorial Lecture before the February meeting of the American Institute of Mining and Metallurgical Engineers.

From this personal history it will be seen that Gillett is a metallurgist with first-rate executive ability who has nevertheless remained a metallurgist and not allowed himself to become primarily an executive. There is something regretful in seeing a fine teacher become dean of some department and get lost in its administration, and it is equally so when a rare researcher turns from his specialty to devote himself mainly to running an organization. Gillett no doubt feels he can be more useful as a metallurgist than as an executive, but the real reason he has chosen to remain a metallurgist is that that is what he likes to be. He has always had the strength to act from simple motives. After the War he received several attractive offers for industrial research work which would have taken him from his job with the Bureau of Mines at Ithaca; he did not accept, simply because he liked Ithaca, he liked the hunting in the surrounding hills, and he wanted to raise his family there.

Doctor Gillett's first love is research. His own inclinations and his associations throughout his career have led him to follow the practical and hard-headed type of investigation as against the theoretical and scientific. He is progressive enough to promote the use of the latest instruments and methods of advanced science, but even here he would prefer to use, for instance, the new electron diffraction method for studying metal surfaces as a means for throwing light on the problem of the corrosion of metals, rather than to clear up old doubts about the "Beilby layer" and the amorphous theory of intergranular metallic cement.

More perhaps than any other metallurgist

Gillett is the exponent of a wide diversity of interests as against narrow specialization. In starting Battelle Memorial Institute he wished its field in metallurgy, fuels, and refractories to be substantially as wide as that of the American Institute of Mining and Metallurgical Engineers. In this his influence has been highly salutary against the day of intense specialization. Few metallurgists can vie with him in sheer erudition, although he himself would smile at the term. He is expert and has made important contributions to the following branches of technology: Electrothermics; brass melting and foundry sand; aluminum and its alloys; fatigue of metals; steel making; alloy steel; high temperature properties of metals; wear resistance; corrosion; heat treatment; controlled atmospheres.

Extremely persistent in research, he never allows a project to become merely the perfunctory job of amassing data. He is ever seeking the hidden kernel of truth, the illuminating idea. Once this is found, he immediately strikes out for a new goal. His greatest satisfaction is in aiding younger men, and many of his contributions are the form of suggestions to others, either associates or those who call for advice.

Gillett likes to write, and his editorial work on *Metals and Alloys* has been an ideal complement to his research work. In this field he has perfected a style of writing that produces a broad review of a field, thus supplementing the usual description of specific results that does not give a view of the state of the art. His term "correlated abstract" for the broader reviews has become familiar. He is a master of this presentation, with surprising conciseness, of the latest information on any subject.

This type of writing is no recent invention, however. In 1925 he produced, in partnership with E. L. Mack, a book entitled "Molybdenum, Cerium and Related Alloy Steels" that is as good an example of that difficult art of "correlated abstract" as any since. It not only reviewed the literature on these steels which had appeared since 1910, to which there were 323 citations, but also contained the result of much new work on the toughness and endurance of the molybdenum steels, specially done to fill a then existing gap in the information. In all respects it was a model for the many recent and excellent publications of the Alloys of Iron Research. It is no accident that the first of those monographs (1932) was on The Alloys of Iron and Molybdenum, and it was prepared by J. L. Gregg as a part of Battelle Memorial Institute's contribution to the project.

Metallurgical writings of today are all too frequently void of artistic merit. It is too bad that the literary influence of Henry Marion Howe has not been as strong as his influence in metallurgy. His concern was with readability as much as accuracy. Gillett's style is in another tradition. Free and easy, it sometimes is so colloquial as to border on the ungrammatical, yet with long usage he has perfected it into a remarkably precise instrument for clearly and directly expressing most intricate ideas. He loves to draw homely analogies and one cannot resist quoting. Likening an organization to a canoe in which the more experienced paddler generally takes the stern:

"There is many a plant and many a laboratory where the craft would make just as much progress if the younger men were given the stern paddle now and then. The stern paddle is not likely to be given up readily; the older man seldom thinks of it and the younger man has too much deference to suggest it. It's not a bad plan to let them try the stern. If they are stern paddlers they're likely sooner or later to go from the bow of your canoe to the stern of some other canoe. While the old steersman's pride may be hurt to sit in the bow, after all on a long cruise it is restful to shift from stern to bow, now and then. We suspect, too, that many people would live to take more and longer cruises if they didn't insist on staying in the stern too long."

His recreations consist of his annual camping and hunting trip to Canada, occasional trap and skeet shooting and fairly frequent bowling. He is a voracious reader of detective stories. A friend in these activities writes: "His bowling game is unique in that he has capitalized on the back-up, bowling right-handed from the left side with a wide curve; his average game is about 140 (possibly for this reason). He plays poker occasionally, he emphatically does not play golf, and does not go to the movies for years." No wonder he feels vaguely ill at ease amid the plush upholstery of hotel life during technical conventions! Continues the friend: "Fishing about Columbus has not been attractive so he turned to trap shooting and more recently to skeet which he considers more sporting. At skeet he breaks more than 20 birds out of a string of 25."

Let us hope that Gil has yet to bag his biggest deer, catch his biggest fish, make his best skeet and bowling scores, and his most important contributions to metallurgy!

ESTIMATION OF HARDENABILITY OF STEEL FROM ITS ANALYSIS AND GRAIN SIZE

By Robert S. Archer
Chief Metallurgist
Chicago District
Republic Steel Corp.

IN TWO preceding installments an attempt has been made first to sketch broadly the history of certain attempts to measure quantitatively the "body" in steel — its ability to harden uniformly, deeply, and consistently, yet toughen well on tempering — and second to develop the concept of "hardenability" and various current methods of measuring it. Further analysis of the problem as discussed at the Symposium on Hardenability at the ⊕ Convention in Detroit will now be given as a conclusion.

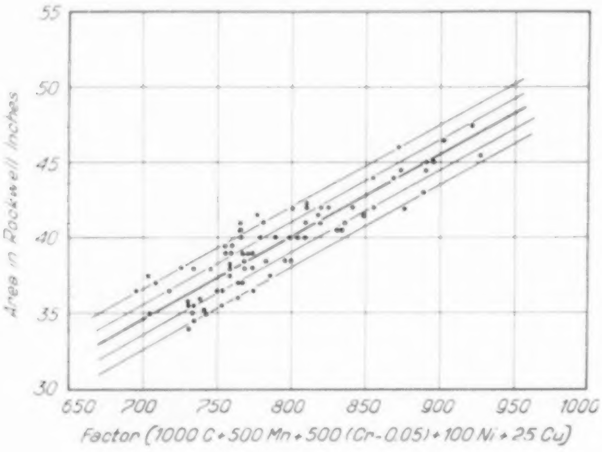
Chemistry and Grain Size

Burns, Moore and Archer published curves in 1937 ⊕ **Transactions** from which hardenability can be estimated quite closely from the chemistry and grain size of a restricted class of plain carbon steels, with due allowance for residual amounts of copper, nickel and chromium. The correlation was based on tests of about 120 heats, all made at the same mill. In this 1938 Symposium, Burns and Riegel (VIII)* present formulae and curves which make the correlation still more exact. Test results were available on steel from three different mills, and were consistent. To the authors this did much to eliminate the possibility that different mill practices might cause considerable differences in hardenability, even with the same chemistry (usual determinations) and grain size. In this paper the effects of carbon and manganese, and of residual amounts of nickel, chromium and copper, are quantitatively expressed for the hypo-eutectoid S.A.E. carbon steels. Separate curves are given for coarse-grained and fine-grained steels in the low carbon, medium, and high carbon range. Curve for the fine-grained, medium carbon steels is reproduced at top of the next page. Silicon, phosphorus, and sulphur are not taken into account because these elements fall within close limits in the steels under consideration.

An interesting and wide difference of opinion regarding the possibility of predicting hardenability from chemistry and grain size was expressed in conversations near the beginning of the convention. Some investigators of the hardenability problem and some metallurgists of long experience in the heat treatment of steel felt that they had too often encountered heats of steel whose response to quenching could not be accounted for by ordinary chemistry or by austenitic grain size. Reasons for this difference of opinion soon developed. It seems that many of the unexplained results were on alloy steels, carburized cases (possibly hyper-eutectoid), or on steels made by somewhat unusual practices. Morris and McQuaid (III) write, "Heats of apparently the same analysis and austenitic grain size will sometimes show a considerable variation in properties, especially in such properties as the Izod value or as-quenched hardness", but add later "especially in alloy steels".

Silicon — That silicon increases hardenability

*Roman numerals refer to the papers in the Symposium on Hardenability, as listed in the box on page 262.



Hardenability of 77 Heats of Fine-Grained, Medium Carbon Steels, as Affected by Minor Variations in Chemistry. Figure 4 of Burns and Riegel's paper (VIII). To derive figure for vertical ordinate the hardness penetration curve of a given steel is plotted against diameter of bar (full size) and area under curve is called "Rockwell Inches"

is well known, since it has long been added to steel commercially for this purpose. Luerssen (IX) cites evidence to this effect pertaining to tool steels. Morris and McQuaid (III) conclude that "low silicon, coarse-grained steels will not harden any better than fine-grained steels of standard silicon content", but also point out: "One of the effects of very low silicon is to increase the oxygen content in steel, especially in the absence of aluminum." This is pertinent to the statement by A. S. Jamieson, in discussing the paper by Burns and Riegel, that semi-killed steels show 5 to 6 less "Rockwell Inches" (area under the hardness-penetration curve) than steels of otherwise similar composition but containing in addition 0.15 to 0.30% silicon.

Grossmann, Asimow and Urban (II) report that an increase of silicon from 0.16 to 0.33% increased the "ideal critical size" from 1.27 to 1.44 in. for a coarse-grained steel containing 0.61% carbon and 0.85% manganese.

Phosphorus — The effect of phosphorus on hardenability is less known, so we are especially indebted to the same three authors for new data. Increasing phosphorus from 0.020 to 0.097% increased the ideal critical size from 1.61 to 2.00 in. for a coarse-grained steel with 0.62% carbon and 0.98% manganese.

COMPLETING his review of the recent ⊕ Hardenability Symposium, R. S. Archer shows how it is now possible to predict the hardenability of a heat of carbon steel, while it is yet in ingot form, from its chemical analysis and its grain size as deduced from furnace practice — a matter obviously of great importance to a manufacturer in meeting modern specifications for engineering steels in every-day production.

Aluminum — The exact effects of this element still seem to be uncertain. We are here concerned with the small amounts of aluminum, usually less than 0.10%, added to steel for deoxidation and control of grain growth. Careful analytical procedure is required to determine even the total aluminum accurately in such small amounts, and it is still more of a problem to learn in what form the aluminum is present. We may obviously have metallic aluminum in solid solution, free Al_2O_3, or the same oxide combined mechanically or chemically with other inclusions. Some of the aluminum might also be combined with nitrogen, sulphur or carbon. Morris and McQuaid (III) report analytical results in terms of Al_2O_3 and "aluminum", or "metallic aluminum".

W. Crafts and J. L. Lamont in another paper at the ⊕ Convention ("Some Effects of Deoxidizers in Low Carbon, 1.5% Chromium Steel") refer more cautiously to "total aluminum" and "acid-soluble aluminum" in 10% sulphuric acid. The acid-insoluble portion is considered to represent inclusions of appreciable size, such as are seen under the microscope. In both of these papers, it seems to be the acid-soluble aluminum which gives the best correlation with hardenability and other properties.

Morris and McQuaid report 0.014% Al and 0.0046% Al_2O_3 for a certain fine-grained heat, and 0.002 Al and 0.0054 Al_2O_3 for an ingot at the end of the same heat which reverted to the coarse-grained type. In low carbon, 1.5% chromium steels, Crafts and Lamont found 0.01% acid-soluble aluminum sufficient to develop the fine-grained condition. Grossmann and his co-workers (II) added various amounts of aluminum to different ingots of a commercial heat to which no aluminum had been added in the ladle. The heat contained 0.62% C, 0.87% Mn, and 0.14% Si. A mold addition of 1 lb. of aluminum per ton (0.045%) decreased the "ideal critical size" from 1.39 to 0.88 in. This decrease in hardenability was attributed to grain refinement.

Morris and McQuaid conclude that the shallow hardening effect of small aluminum additions "is not primarily due to the physical size of the austenite grain but is dependent upon other factors of which we at present know little". They seem to feel that aluminum may be concentrated in the grain boundaries formed at the end of freezing or of hot working, and that this prevents the complete car-

burizing by diffusion of these old grains during heating for hardening. The low carbon boundary regions thus supposed to exist at the time of quenching would have high critical cooling rates and therefore lead to decreased hardenability. Grain boundary ferrite adjacent to martensite in quenched S.A.E. 1040 steel is cited in support of this view.

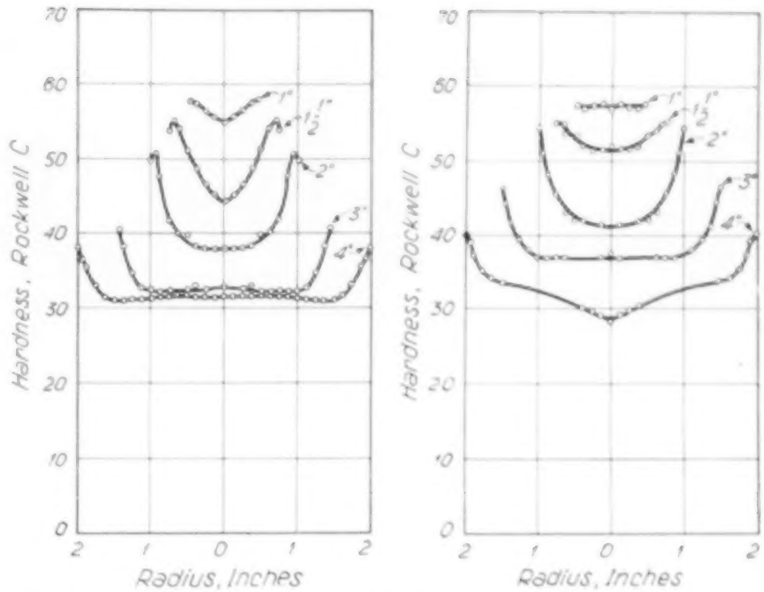
Closely related to the above are observations by Crafts and Lamont. After quenching their 1.5% Cr steels in oil and drawing at 300° F., they found the tensile strength to drop sharply as the acid-soluble aluminum increased from 0.012 to 0.025%. "It is notable that the drop in tensile strength occurred at a higher aluminum content than that which produced the maximum degree of grain refinement." From microscopic examinations and dilatometric measurements during quenching, these investigators concluded that increased contents of aluminum increased the ferrite, slightly decreased the pseudo-martensite, and increased the martensite.

Morris and McQuaid state that aluminum in sufficient quantity increases hardenability, providing temperature and time in heating for hardening are sufficient to insure complete carbon solution and diffusion. The quantity of aluminum they have in mind is indicated by their reference to nitriding steel. Grossmann's results were as in the adjoining table, where total aluminum is by analysis and

Addition Lb. Per Ton	Total Aluminum	A.S.T.M. Grain Size	Ideal Critical Size
0	0.002%	3.5	1.39 in.
¼	0.002	4.0	....
½	0.019	6.0	....
1	0.045	6.0	0.88
2	0.109	6.0 (4 to 6)	1.08

grain size is that of the quenched bars, judged by fractures. The increase in hardenability produced by increasing the mold addition from 1 to 2 lb. per ton is attributed to a slight coarsening of the grain and to the effect of alloyed aluminum.

There is agreement that aluminum decreases hardenability up to the amount just enough to produce maximum grain refinement, and that sufficiently larger amounts increase hardenability. It is not clear, however, just how much of an excess of aluminum over the minimum grain refining quantity is required to reverse the trend; in fact, the reported results are contradictory, ranging from about 1 to 4 times the minimum quantity to produce maximum grain refinement.



Hardness Traverses of Various Sized Bars of S.A.E. 3145 (Left) and 5145 (Right). Oil quenched from 1530° F. (Jominy, IV)

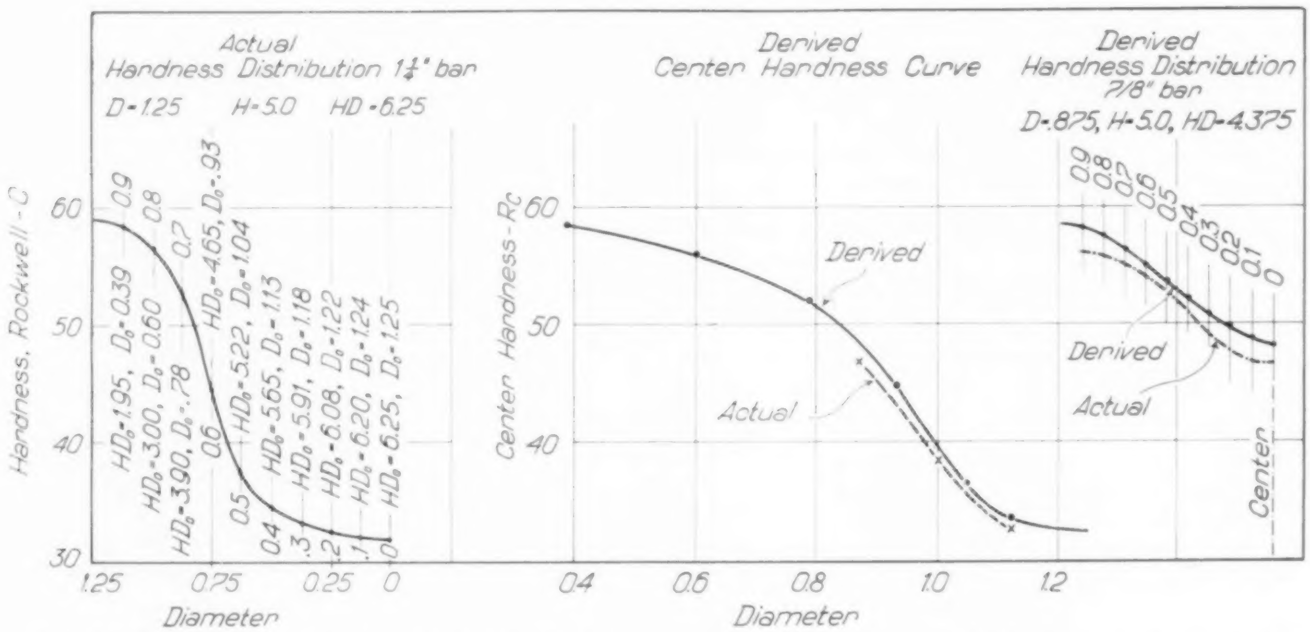
Hardenability of Alloy Steels

There has been some lack of published data on hardness distribution in as-quenched bars of alloy steels. Contributions on this subject in the 1938 Symposium are therefore welcome. Gordon T. Williams (VI) gives Rockwell C values across 2-in. and 3-in. bars of S.A.E. 3150 and 4150, both air cooled and oil quenched. Jominy (IV) publishes results on 1, 1½, 2, 3 and 4-in. rounds of S.A.E. 3145 and 5145 quenched in oil. Crafts and Lamont (V) give some values for various steels containing up to 3% chromium.

An interesting observation by Jominy, and shown in Fig. 9 and 10 of his paper (IV) reproduced at the top of the column, was that his S.A.E. 3145 steel showed lower Rockwell C number than his S.A.E. 5145 steel at the higher cooling rates, but that this relation was reversed when quenched at lower cooling rates. For example, a 1½-in. round of S.A.E. 5145 showed Rockwell C-52 at the center, while the value for S.A.E. 3145 was only 45. In 4-in. rounds, however, the S.A.E. 3145 was C-32 at the center as compared with C-28 for the S.A.E. 5145 steel.

Hardening Versus Cooling Rate

It has been assumed by many investigators that, with respect to the quenching operation itself, it is the cooling rate alone which determines the degree of hardening. This assumption is of course basic in any attempt to estimate penetration from calculated cooling rates, as Grossmann has done, or even from observed cooling rates. Now it is possible that factors other than cooling rate are involved, such as pressure and internal stresses



Correlation Between Derived and Actual Hardness-Depth Curves (Grossmann, Asimow and Urban) for Quenching Conditions Giving Heat Transfer Equivalent H = 5.0 (Related to Severity of Quench). Curve at left is determined by experiment for 1¼-in. dia. bar of 0.41% C steel. At 0.4 of the radius its hardness is about C-34, and this hardness is related to the cooling velocity at that point. By reference to certain "detailed characteristic curves" this cooling velocity is found to be sufficient to harden completely (to a structure of half martensite, half pearlite) a bar of this steel 1.13 in. dia. (Do = 1.13) and its hardness at center would also be C-34. Thus one point is determined as the "Derived Center Hardness Curve", the middle one above. Three actual determinations check this derived curve fairly well. Allied methods are used to derive the hardness distribution in a ⅞-in. bar of this steel in a quench of same severity (shown in the curve at the right, above)

developed by rapid cooling. It is therefore important to know to what extent hardening can be directly correlated with cooling rate.

Referring to his entire scheme, Grossmann (II) states: "Data from steels of a variety of hardenabilities, quenched under various conditions, indicate that useful correlations can be made." It should perhaps be kept in mind that his experiments were apparently limited to *round* bars, under which condition factors other than cooling rate might remain fairly constant. For example, "derived" and "actual" curves of *center* Rockwell values in his Fig. 22, reproduced on this page, agree well; derived and actual curves for a Rockwell traverse across a section ("U" curves in the same figure) also agree fairly well, but not as closely as actual curves should agree in accurate hardenability testing.

The relationship between cooling rate and hardening is of importance in applying Jominy's test to the quenching of rounds and other shapes, and Jominy presents interesting results in his paper, IV in this symposium. Cooling rates at various distances from the water-cooled end of his 3-in. long specimen were measured, and were found to vary from over 420° to less than 4.5° F. per sec. Cooling rates at the center of various sized rounds quenched in the ordinary way were taken from the published work of French and Scott, and from new experiments. "Quite good agreement exists between the center hardness of the various bars with the hardness on the hardenability bar (General Motors Corp. test) at the locations of corresponding rates of cooling." This is illustrated, for example, in his Fig. 8, reproduced at the head of the next page.

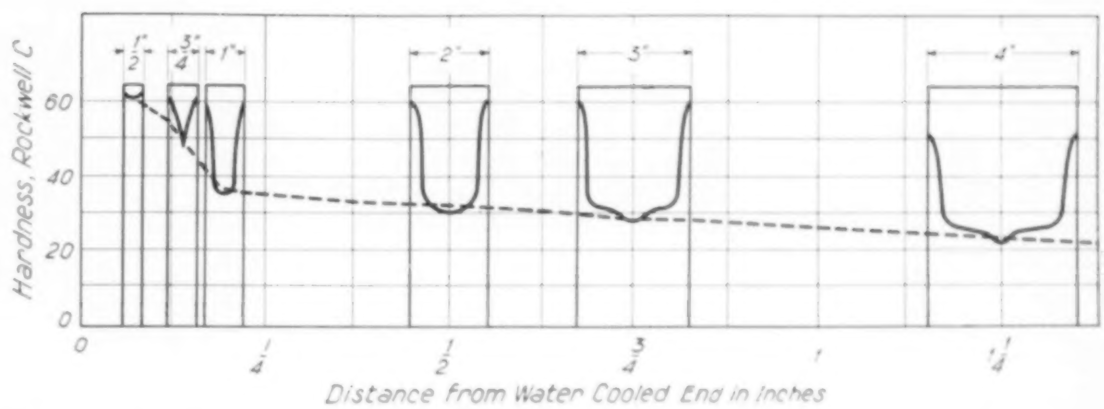
Most of Jominy's correlations involved cooling rates slower than those at and near the surface of bars quenched vigorously in water, so perhaps conclusions should be reserved with respect to these very high cooling rates. G. V. Luerssen touched briefly upon the possible effects of stresses in the discussion following his own paper (IX).

Effects of Tempering and Mechanism of Austenite Decomposition

E. H. Engel brought out the fact that softening on tempering is more rapid the harder the quenched structure. ("The Softening Rate of a Steel When Tempered From Different Initial Structure"; Ⓐ Detroit Convention paper.) For this reason, he finds that after tempering 50 or 100 sec. at 1200° F., the surface Rockwell C value of a previously quenched 11/16-in. bar of 0.74% carbon steel is actually lower than near the center; ordinary pearlite is more resistant to softening and spheroidizing than martensite and troostite. Williams' U curves (for example, his Fig. 1 in paper VI) on specimens drawn at temperatures up to

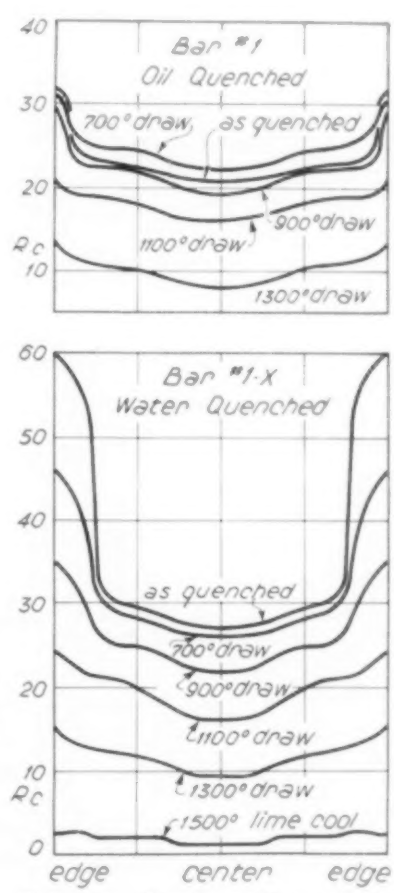
1300° F. generally showed the highest Rockwell values still at the surface, although the differences, surface to center, are less than in the as-quenched condition.

Mechanism of austenite decomposition is discussed at length from a theoretical standpoint in the stimulating paper (I) by R. F. Mehl. The discussion is restricted to austenite of eutectoid composition, and is admittedly quite speculative. Some might not agree with the author's assertion that "the major facts of practical usefulness in the hardening of steel are well known", but at least enough are to form a basis for his interesting discussion.



Hardenability Test Used by General Motors Corp. Cools One Faced End Only of Hot Bar by Water Spray; Hardness of Surface Plotted Against Distance From Hot End Gives a Curve Such as Shown Dotted Above. These data check the center hardness of fully quenched bars, cooled at corresponding rates through 1300° F. (Fig. 8 of Jominy's paper, IV)

It is proposed that the formation from austenite of the lamellar products (troostite, sorbite and pearlite in the conventional nomenclature) is nucleated by cementite. Nucleation is said to take place exclusively at austenite grain boundaries in silicon-killed carbon steels and in steels of high purity prepared in the laboratory. General nucleation takes place in "aluminum-killed steels, steels heavy with inclusions, and steels bearing undissolved carbides". Mehl's analysis of the isothermal reaction rate curves is restricted to the case of grain boundary nucleation. The nodules are said to extend only into the grain in which the nucleus forms, not crossing the austenite grain boundary during growth. The process discussed is thus one of nucleation at boundaries and radial (edgewise) growth toward the center of the grain. Analytical expressions are developed to show the effect of (1) grain size, (2) rate of nucleation, and (3) rate of growth on the form of the isothermal reaction rate curve. The latter is plotted in a family of curves, Fig. 6 of his paper, reproduced in last month's installment.



U-Curves, Hardness Versus Penetration, of 2-In. Rounds of 1050, After Various Quenching and Tempering Treatments Noted. (Fig. 1 of Williams' paper, VI)

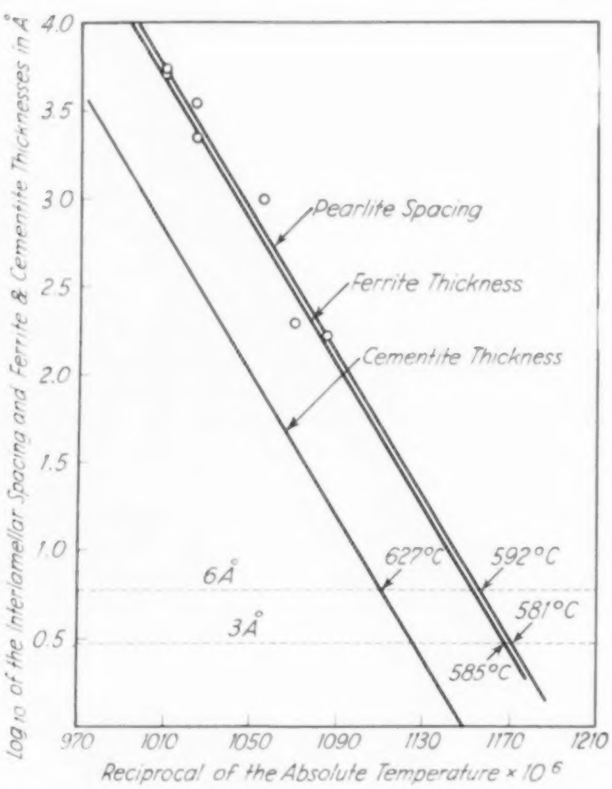
An interesting point is that while the grain radius *a* varies only over a range of 1 to 23 for a variation in A.S.T.M. grain size from No. 10 to No. 1, the rate of growth factor can vary by many orders of magnitude, because of either a change in the temperature of reaction or the addition of alloy elements. "It is in this circumstance that lies the reason for the fact that the effect of grain size on the rate of reaction is a minor one compared to the effect of alloying elements."

When a nucleus forms, a new interface is created, the work required to form the interface being furnished by the free energy change of the reaction. This work varies with the radius of the nucleus, passing through a maximum at a certain radius. When a "nucleus" is smaller than this critical size, it will redissolve, but larger nuclei persist and grow. Energy considerations indicate a relationship between temperature and the number and size of nuclei; nucleation rate is maximum at a certain degree of undercool.

In alloy steels, Mehl holds that the alloy element must diffuse either to or away from the point of nucleus formation. Since nickel is not an element forming carbides, the stable cementite nucleus will form only when the carbon atoms have diffused to the point of formation, and the nickel atoms away from this point. The probability of the formation of a nucleus is then less than when iron and carbon alone are present and the carbon atoms alone need diffuse. In the case of manganese, an element forming carbides, the manganese

atoms would have to diffuse *toward* the point of formation, again decreasing the probability.

Similar reasoning is applied to the rate of growth after nucleation. Data are cited to show that the diffusion coefficient of carbon in austenite is only very slightly affected by alloy elements. On the other hand, the diffusion coefficient of nickel at 1000° C. is said to be only about one-hundred-thousandth of that of carbon at the same temperature. Hence it is held that the decreasing rate of growth of the lamellar structures with increasing alloy content cannot be dependent upon a decreased rate of carbon diffusion and can only be explained by the necessity for the diffusion of the alloy elements themselves.



Variation of Dimensions of Pearlite According to Temperature of Its Formation. (Fig. 20 of Mehl's paper, I)

Mehl thus postulates that the retarding effect of alloys upon both nucleation and growth — that is, their deep hardening effect — is due to the principle that the carbides formed during quenching must contain their proper proportions of carbide-forming elements, and must be free from those other elements that are not considered to form carbides. This interesting hypothesis must be subject to experimental verification. It would seem that after slow cooling or prolonged tempering, the carbide constituent should contain more of the carbide-forming elements, and less of the others, than the steel as a whole. On rapid cooling, however, some of the alloy elements which normally would be in solution in the iron, might be trapped in place. In other words, the formation of carbide may not require the diffusion of alloy elements, and the present reviewer understands that nickel has been found in carbides separated from certain toolsteels to which nickel was added. The question suggests analytical work on carbides separated from rapidly cooled alloy steels.

The hardness of the lamellar constituents varies with the interlamellar spacing. In the accompanying reproduction of Mehl's Fig. 20 the log of the spacing plotted against the reciprocal of the absolute temperature gives a straight line. Extrapolation to low temperatures shows that atomic dimensions are reached at 150° C. below Ae_1, at which the decomposition of austenite reaches a maximum rate and the formation of lamellar structures ceases. Mehl suggests that the thickness of the cementite lamellae is a measure of the size of the stable cementite nucleus. The reason why lamellar structures cannot form below a certain temperature is that the stable nucleus cannot then be as large as the unit cell of cementite.

"The formation of martensite at low temperatures appears never to be wholly complete, for there is always some retained austenite, and the curve marked 'Transformation Ends' in the familiar 'S' diagram should probably not have been included in the diagram." The dark acicular structure formed at transformation of austenite within the range between 400 and 200° C. forms, according to Mehl, by the same mechanism as martensite except for rapid decomposition of the tetragonal lattice during the reaction.

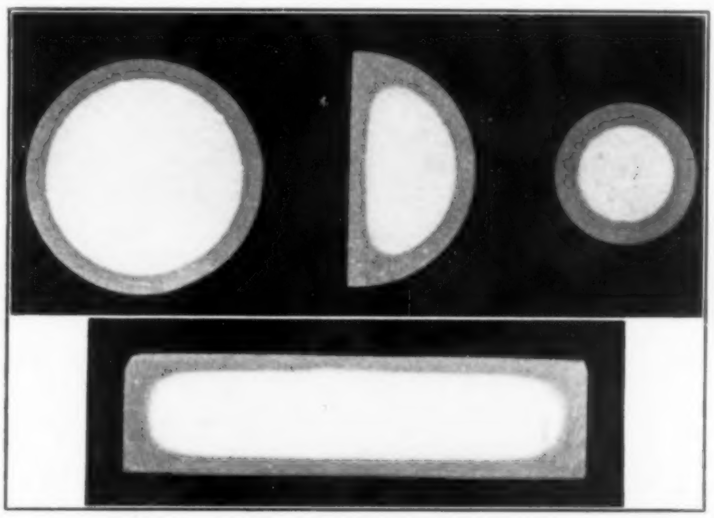
Some Practical Applications

In the papers by Grossmann, Asimow and Urban (II), Queneau and Mayo (VII), and Burns and Riegel (VIII), methods are given for estimating hardness penetration in steel rounds of various sizes. Luerssen and Queneau both refer to relationships in the cooling rates of spheres, plates and round cylinders as stated by H. J. French in his

Papers in the Symposium

I. PHYSICS OF HARDENABILITY, by Robert F. Mehl
II. HARDENABILITY, ITS RELATION TO QUENCHING, by M. A. Grossmann, M. Asimow and S. F. Urban
III. EFFECT OF THE SILICON AND ALUMINUM ADDITION, by M. J. R. Morris and H. W. McQuaid
IV. HARDENABILITY TESTS, by Walter E. Jominy
V. HARDENABILITY OF LOW CHROMIUM STEELS, by Walter Crafts and John L. Lamont
VI. TRANSVERSE HARDNESS TESTS, by Gordon T. Williams
VII. THE HARDENABILITY LINE, by B. R. Queneau and W. H. Mayo
VIII. HARDENABILITY OF PLAIN CARBON STEELS, by John L. Burns and Glen C. Riegel
IX. HARDENABILITY IN LIGHT SECTIONS, by G. V. Luerssen

book on The Quenching of Steel. The conclusion of Queneau and Mayo that the depth of hardened case on a flat is $\frac{2}{3}$ of that on a round of diameter equal to the thickness of the flat does not appear to follow directly from French's relationships, but appears to be approximately true in their experiments, although it holds better for one of their steels than another. Luerssen shows interesting sections of two rounds, a half-round, and a flat (his Fig. 3, reproduced on this page). Penetration from the flat face of the split $1\frac{1}{4}$-in. round (thickness $\frac{5}{8}$ in.) is about the same as from the face of a $\frac{5}{8}$-in. slab. Penetration from the curved surface of the split round is substantially the same as for the full $1\frac{1}{4}$-in., round, and almost 50% greater than from the flat face. Luerssen concludes that in these small sections the shape of the piece is the governing factor and not mass.



In Small Sections Penetration of Hardness Is More Dependent on Shape Than on Mass (Luerssen, IX, Fig. 3). Dimensions are: 1.25-in. round, same split, 0.75-in. round, 0.625-in. slab

Jominy (IV) determined the rate of cooling at the center and base of the gear tooth in the Chevrolet rear axle drive pinion, and found it to be 55° F. per sec. Hence if full hardening at the center is desired, a steel is required which fully hardens at a rate of 55° per sec. in Jominy's hardenability test. Since it is not convenient to make cooling rate tests on many service parts, he suggests that the part in question and a hardenability bar be made from the same bar of steel, and the distance found on the hardenability bar which corresponds in hardness to whatever point is desired in the service part. From his Fig. 8 (reproduced on page 261) it will be seen that this distance corresponds to a certain rate of cooling which is then approximately the rate for the service part.

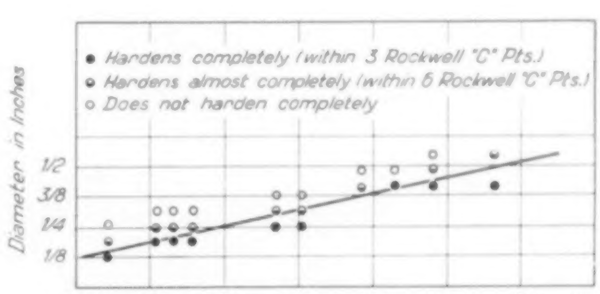
Burns and Riegel (VIII) consider in detail three specific applications of steel and show how the proper steels may be selected through the use of their formulae relating hardenability to analysis and grain size, and their charts for penetration. One of the latter is reproduced below.

Conclusion

It has been shown that the hardenability of hypo-eutectoid, commercial, basic openhearth, carbon steels made with the usual additions of silicon and aluminum for deoxidation and grain refinement (fine-grained type), normalized and then hardened at customary temperatures, can be predicted from the chemical analysis with sufficient accuracy for all ordinary purposes. This is also true of similar steels known to coarsen under the actual conditions of hardening. Uncertainty exists, however, in the case of steels known to be coarse-grained only in the McQuaid-Ehn test (at 1700° F.) because such steels may be fine-grained when quenched from some lower temperature.

In hyper-eutectoid carbon steels or carburized cases the problem is complicated by the marked effect of carbide form and distribution prior to heating for hardening, together with the fact that greater differences in carbide form and distribution are apt to exist than in medium carbon steels given the usual normalizing treatment before hardening. It seems likely that the hardenability of carbon toolsteels can be predicted with at least approximate accuracy from their analysis, grain growth characteristics, and structure or treatment prior to hardening.

Alloy steels involve further problems, and more information is needed with regard to the specific effects of the various alloy elements on hardenability, both alone and in various combinations. Since the possible combinations are almost infinite, it will perhaps be most fruitful to study intensively the much more restricted combinations in commercial steels. *(Turn to p. 278)*



Relationship Between Size of Bar and Chemical Composition for Complete Hardening of Fine-Grained Steel May Be Determined From Above Curve. (Fig. 16 of Burns and Riegel's paper. VIII)

MUCH METAL

Picture Story
By Shirley Ware

Photographs by
Hedrich-Blessing Studio

Chicago

The old structure the architect had ← to work on

The Michigan Ave. facade got its face lifted thus

USED TO MODERNIZE OFFICE BUILDING

METAL played an exceedingly important role in the $300,000 modernization program on what is now the Fairbanks Morse Building in Chicago. George T. Senseney, the architect, turned to modern metals wherever their use was indicated by requirements of durability, fire protection or esthetics. All furbelows were removed from the old exterior up to the limit of normal view of passersby on the Avenue. Aluminum and bronze harmonized beautifully with the smooth stonework and plate glass of the new, rigorously simple design. Anodic protection for the metal in such an exterior will reduce the maintenance to a minimum, since it is practically impervious to weather . . . . . The entire ground floor, open to a high ceiling and surrounded by

And the ground floor turned into an exhibit with appropriate mechanistic decor

Nowhere is the contrast between the gay nineties and the smug present more vivid than in the elevator call buttons . .

Elevator Lobby; Before and After

an interesting balcony, is given over to the display of Fairbanks Morse products. Economical reconstruction required the retention of two main building columns in the middle of the area, but Mr. Senseney worked them into a massive porch enthroning the principal exhibit and concealing the air conditioning equipment. The entire design of fixtures is functional and care is taken to reduce maintenance labor

to a minimum. Aluminum furring is used on the walls and in the indirect lighting fixtures; balcony railings and all lettering and nameplates are of metal . . . . . Carrying out these general principles elevator lobby and cabs were walled with wood veneer and trimmed with aluminum and bronze . . . . . Stairwells were renovated very simply by encasing the iron handrail and installing indirect lighting fixtures of "alzak" brightened aluminum for maximum reflectivity — all very carefully fluted and molded to harmonize with the shapes used around the elevator doors . . . . . Lavatories are in burnt

Venetian Blinds for the Boss;
Opalescent Glass for the Help

sienna, porcelain and chromium plate. Enameled steel wall panels have joints caulked with white mastic, a combination durable as marble in public service. Sink supports, plumbing fixtures and builders' hardware are all chromium plated — the architect's ideal as to durability, sanitation, and maintenance . . . . . Low partitions in general clerical offices are of metal; hollow base boards and door casings, removable with a screw driver, conceal telephone and other electrical wiring. In the president's office the decorator effectively combines metal blinds, fixtures, chairs and safe.

Sigma Phase in the Fe-Ni-Cr System

Proposed by John S. Marsh

Fig. 2 (at right) — Section Through Space Model at Temperature Limit of Existence of Sigma Phase. k_1k_2 is an isothermal straight line

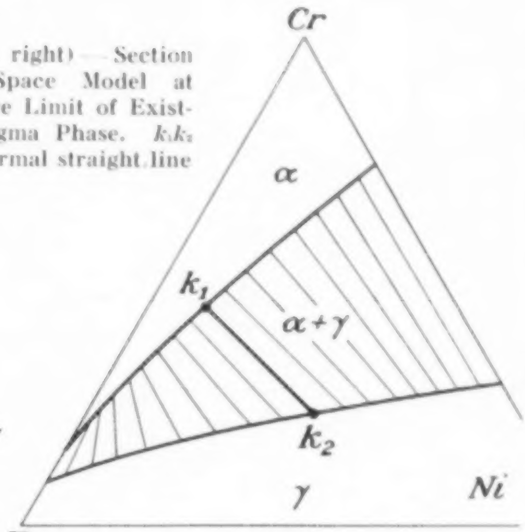


FIG. 2

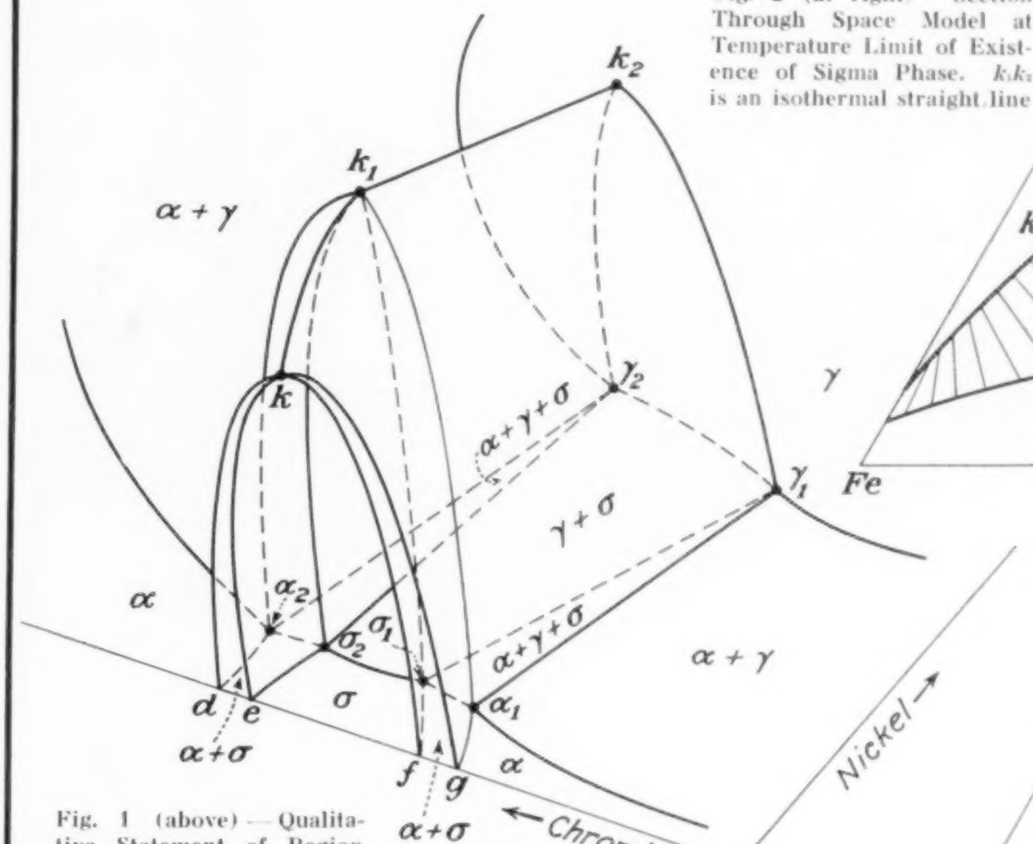


FIG. 1

Fig. 1 (above) — Qualitative Statement of Region Containing Sigma Phase, Worked Out by Thermodynamic Principles, in Iron-Nickel-Chromium System. Curve *ekf* represents limits of sigma phase in iron-chromium plane. For further description see text of Marsh's letter (page 271)

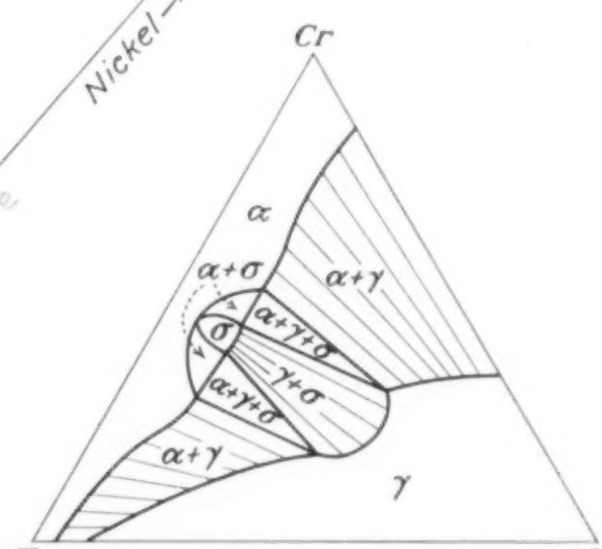


FIG. 3

Fig. 3 (above) — Section at Temperature Between That of k and k_1, Too High for Sigma Phase to Occur in Nickel-Free Alloys

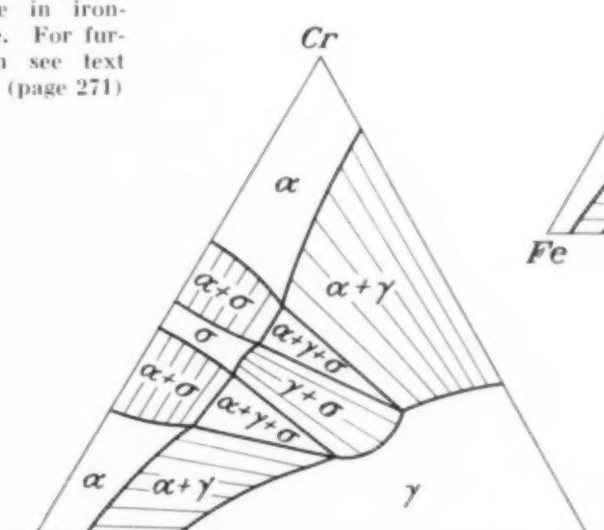
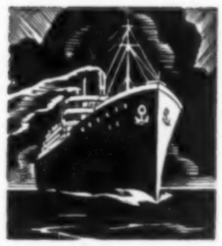


FIG. 4

Fig. 4 (at left) — Sections at Temperature Below k, in Region Where Sigma Phase Is Stable in the Iron-Chromium System. Probably a true qualitative representation of the Fe-Ni-Cr ternary diagram at ordinary temperatures



CORRESPONDENCE AND FOREIGN LETTERS

Limits of a New Phase in the Fe-Ni-Cr system

Special Letter to METAL PROGRESS
by JOHN S. MARSH
Physical Metallurgist for ALLOYS OF IRON RESEARCH

NEW YORK, N. Y. — The existence of an intermediate phase in the iron-chromium system, generally denoted "sigma" by the Greek letter σ, has been established definitely. For a comprehensive review of the matter see Kinzel and Crafts' "The Alloys of Iron and Chromium". Several investigators have indicated the presence of this phase in the important iron-chromium-nickel diagram, but no presentation has yielded entirely to the dictates of thermodynamic principles. Since the participation of the sigma phase leads to a ternary diagram of a type that is probably unfamiliar to many metallurgists, it seems worth while to show the probable form of the region containing the sigma phase, even though there are no data as yet which permit accurate establishment of the various boundaries. However it is unlikely that the qualitative details of the construction will be changed, and others may later be saved the chore of thermodynamic analysis. Reference is therefore made to the sketches on page 269.

The construction is guided by several experimental observations: One is that the intermediate phase is found over relatively wide ranges in the composition triangle of such systems as Fe-Cr-Ni, Fe-Cr-Mn, Fe-Cr-Si, and Fe-Ni-V. Another is that nickel probably increases the temperature range of stability of the phase. This is sufficient information to permit construction of the qualitative, but permissible, diagram shown in Fig. 1 of the data sheet, page 269, in which the region of interest may be imagined as a sort of double walled tent with its entrance in the iron-chromium plane. The inner part of the door is bounded by the curve ekf, or the boundary of the sigma phase region of the iron-chromium diagram. The outer part is the curve dkg, or the boundary between the alpha region and the alpha plus sigma region. Point k is common to both curves at their maximum. The remainder of the entry-way is bounded by the doubly curved surfaces $d\alpha_2k_1\alpha_1gk$ (the outer) and $e\sigma_2k_1\sigma_1fk$ (the inner); these surfaces osculate in the line kk_1.

The walls of the tent proper are the singly curved surfaces $\alpha_2\gamma_2k_2k_1\alpha_1\gamma_1$ (the outer) and $\sigma_2\gamma_2k_2k_1\sigma_1\gamma_1$ (the inner); these surfaces osculate in the isothermic straight line (tie line) k_1k_2. Furthermore they are ruled surfaces, generated by isothermic straight lines rolling along related lines of two-fold saturation, namely, $k_1\alpha_1$-$k_2\gamma_1$, $k_1\sigma_1$-$k_2\gamma_1$, $k_1\sigma_2$-$k_2\gamma_2$, and $k_1\alpha_2$-$k_2\gamma_2$. Surfaces $k_1\sigma_1\alpha_1$ and $k_1\alpha_2\sigma_2$ are ruled also.

Several schematic isothermic sections of this fragment of the solid model were con-

structed in order to illustrate further the nature of the sigma phase region. The first of these, Fig. 2, is at the temperature limit of existence of sigma phase upon approach from below, which is to say that the plane of the section includes line k_1k_2. This section is characteristic of Fe-Cr-Ni alloys at those temperatures in which only alpha and gamma phases exist. The left hand terminals of the phase boundaries are shown to lie in the gamma loop of the iron-chromium diagram. This assumes — neglecting the temperature minimum of the loop, which introduces no complication — that k_1k_2 lies at a temperature greater than that of the alpha → gamma transformation of iron. Otherwise the terminals lie in the iron-nickel plane.

It may be noted in passing that the rate of transformation to sigma phase is low, consequently combinations of phases existing at high temperature are easily preserved at low temperature. This is the reason that many of the proposed sections of the iron-chromium-nickel diagram at low temperature are similar to Fig. 2 (after shifting the left hand terminals of the phase boundaries to the iron-nickel plane), and the reason for the belief that sigma phase may never appear in alloys undergoing ordinary mill treatment. The phase may appear in alloys of favorable composition in elevated temperature service, however.

Figure 3 is a section at a temperature lying between those of points k_1 and k, that is, the temperature exceeds that at which sigma phase becomes stable in the iron-chromium system. The phase does appear, however, upon addition of nickel. Intersection of the plane of the section with the various ruled surfaces gives rise to the familiar triangular regions containing three phases. Figure 4 is a section at a temperature below that of point k; it is probably a true representation, for equilibrium conditions, of the phase regions of the iron-chromium-nickel diagram at ordinary temperatures. (The sigma phase region of the iron-nickel-vanadium diagram may be expected to be similar.)

John S. Marsh

Proportions of Openhearth Furnaces

Special letter to Metal Progress
by Federico Giolitti
Bessemer Medalist; Consulting Engineer

Turin, Italy — For a long period of time European practice in the construction of openhearth steel furnaces followed various designs, not only in different countries, but also in different regions of the same country. Only after the War came some standardization.

When one considers our fragmentary knowledge of the physical and chemical data on which a rational construction should be based, it is evident that any standardization can only have a purely empirical character at the present time, being simply the result of a great number of careful observations and practical data obtained with different types of furnaces working on different classes of steel. Even so the results obtained may acquire some importance, although limited to simple details of construction. In fact, in this instance — as in any other process of empirical selective elimination — fixing a few points of apparently secondary importance may form the basis for determining other essential elements.

This seems to justify a brief survey of items that may be considered as definitely fixed in the present state of European openhearth construction. For evident reasons this survey must be limited to very few elements, taken essentially as typical examples.

One of the points where a uniform practice may be considered as being generally adopted (with the exception of those works where special processes are operated) is the one concerning the form and proportions of the hearth.

For basic furnaces the ratio between the average and the maximum depth of the bath varies between 0.85 and 0.4. The highest limit quoted is reached very seldom, and only in furnaces designed for maximum output where the quality of the steel is of secondary importance.

When the ordinary carbon steels to be produced must conform to certain quality requirements (and especially to those connected with further cold working) the ratio generally adopted is about 0.6.

For the production of alloy steels or carbon steels of a very high quality (for cold drawing and deep stamping) a ratio of 0.5 is the more usual one.

The lowest values — though seldom reaching the limit of 0.4 — are adopted for the manufacture of high quality alloy steels, especially for medium sized furnaces.

It is thus seen that the bottom contour of the hearth is reasonably well fixed, depending

on the quality of the steel it is desired to make.

A second point is really connected with the preceding, and applies to furnaces of a given type used for the production of a given class of steels. This concerns the ratio between the surface of the bath and its maximum depth. A study of a great number of existing furnaces has led to a very interesting paper published by L. Bruno in *La Metallurgia Italiana* (December 1937). The author reaches useful conclusions concerning the values usually found for the ratio between the square root of the surface of the bath in square meters and its maximum depth in meters.

A ratio of 12.5 corresponding to a very shallow bath is seldom adopted, and only for low grade production. For ordinary low carbon steels this ratio is approximately 11.5. A ratio of 10.8 is found for all classes of steels, but only when ordinary quality is required. For high quality steels the ratio may be as low as 8.7, and lower values are very seldom adopted, because in all cases where they could be justified by the high quality of the steel to be produced, the openhearth is usually replaced by the electric furnace.

Certain other details of furnace construction are more or less standardized:

Multiple gas and air ports have been abandoned. The angle between the single gas port and the air port is practically constant at 20°. The bottom of the gas port is never closer than 12 in. to the surface of the bath. The height of the roof above the bath is constant for furnaces of the same size, and included between the rather narrow limits of 5 ft. 10 in. for 8 to 10-ton furnaces and 6 ft. 6 in. for 100-ton furnaces. The length of gas flues to the hearth is nearly always 10 ft. The "Terni" construction of furnace ends, with standardized dimensions, has been adopted by a great number of European steel works.

For other elements, the process of standardization is still incomplete, but for many of them the variations are included within pretty narrow limits. Such items may be quoted for the normal 30-ton furnaces: Surface of bath from 270 to 325 sq.ft.; charge per sq.ft. of hearth is from 250 to 310 lb.; daily output per sq.ft. of hearth is 1150 to 1500 lb.; length of hearth, 29 ft. 6 in. to 31 ft. 2 in.; inclination of gas ports, 13 to 15°. For furnaces of other sizes the differences between lower and upper limits are about in the same proportion.

Federico Giolitti

Specification for Valve Spring Wire

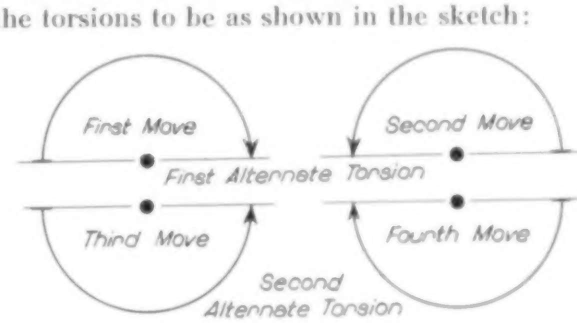
Special Letter to Metal Progress
by A. Oreffice
Chief Engineer, Steel Department of the Fiat Co.

TURIN, ITALY — In the course of many experiments made in the search for a suitable steel wire for making helical valve springs for aero-engines, the writer found a testing method which up to date has given satisfactory results. It may perhaps interest other metallurgists faced with a similar problem.

All specifications now in force for high grade spring wire in Europe and the United States consider ultimate tensile strength, ultimate torsional strength, continuous torsions and reverse bend tests. We rather use, as a mechanical test for acceptance, a specified number of alternate torsions to 180°, combined with a given tensile strength. For each diameter we have established a minimum tensile strength and a minimum number of alternate torsions before failure, as shown in the adjoining table.

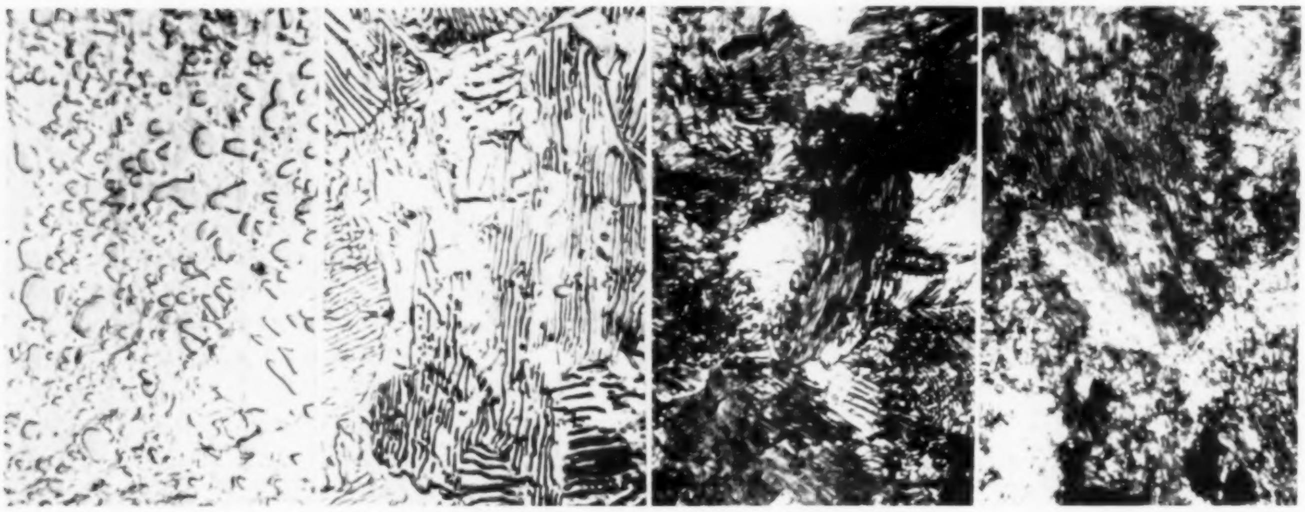
Diameter of Wire	Minimum	
	Ultimate Strength	Alternate Torsions
0.078 in.	270,000 psi.	360
0.098	256,000	320
0.118	242,000	290
0.137	234,000	270
0.157	234,000	230
0.177	234,000	180
0.196	227,000	140
0.216	221,000	120

Such mechanical tests must, of course, be applied to wire before being coiled into springs — that is, to oil tempered wire and hard drawn wire in sample lengths from the reel. The test specimen must have a length equal to 50 times the wire diameter. The torsion test is made on a common wire twisting machine, the nature of the torsions to be as shown in the sketch:



. . . . and so on.

A. Oreffice



No. 1; As Received *No. 2; Muffle Cooled* *No. 3; Air Cooled* *No. 4; Air Blast*

Microstructure of Samples Whose Magnetic

"Troostite" or "Fine Pearlite"
(magnetic behavior of iron carbide)

Special letter to Metal Progress
by O. A. Tesche
Metallurgical Physicist
Randfontein Estates Gold Mining Co.

Randfontein, Transvaal — It is a well-known metallurgical fact that cementite (iron carbide) loses its magnetism on heating to a temperature in the neighborhood of 200° C. The writer thought it might be of considerable interest to study the influence of this phenomenon in samples of one carbon steel heat treated to various microstructural conditions. This, he assumed, would add usefully to the much discussed questions regarding the true nature of such microstructures as pearlite, sorbite and troostite.

The steel experimented upon was a straight carbon steel with about 1.05% carbon. The experimental arrangement was as follows: Rings of 2-in. internal diameter and ¼x¼-in. cross-section were heat treated as set forth below, and then wound with a primary and a secondary winding of 100 turns each. The primary was fed with a 50-cycle alternating current of 1.9 amperes. The e.m.f. generated in the secondary was allowed to act upon an alternating current milliammeter, calibrated to allow a conversion of the readings into volts. The indications thus obtained are roughly proportional to the average permeability of the metal forming the ring.

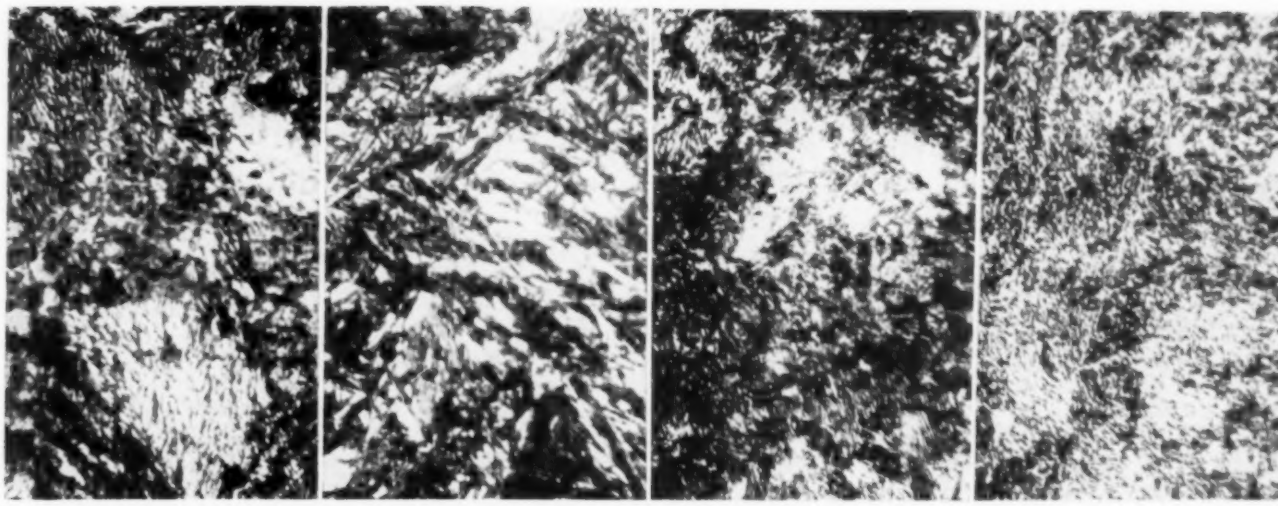
During an experiment, one of the rings was heated to about 250° C. in an electric muffle furnace; then the furnace, with the ring, was allowed to cool naturally. A thermocouple indicated the temperature. Readings from the milliammeter were obtained during this cooling period, the primary current being kept constant at 1.9 amperes, and the results plotted against temperature.

Eight rings were thus examined. These were in the following states, or had the preliminary heat treatment noted:

1. As from factory — Rockwell B-96.
2. Heated for 35 min. at 900° C. (1650° F.) and cooled in the muffle — Rockwell C-14.
3. Heated as under 2, but cooled in still air — Rockwell C-31.
4. Heated as under 2, but cooled in compressed air — Rockwell C-34.
5. Heated as under 2, but quenched in oil — Rockwell C-47.
6. Heated as under 2, but quenched in brine — Rockwell C-61.
7. Treated as under 6, and tempered for half an hour at 400° C. (750° F.) — Rockwell C-45.
8. Heated for 35 min. at 900° C. (1650° F.) and austempered at 400° C. (750° F.) in molten lead for half an hour — Rockwell C-49.

Treatments 2 to 6 are arranged in an order of increasing cooling speed. The structures obtained in the small rings might be expected to be, according to customary nomenclature, lamellar pearlite, sorbite, fine sorbite, troostite and martensite.

The microstructures actually observed are shown in the accompanying micrographs, at 1500 diameters. The steel in its original state is spheroidized. The muffle, air, compressed air, and oil cooled samples are all of lamellar



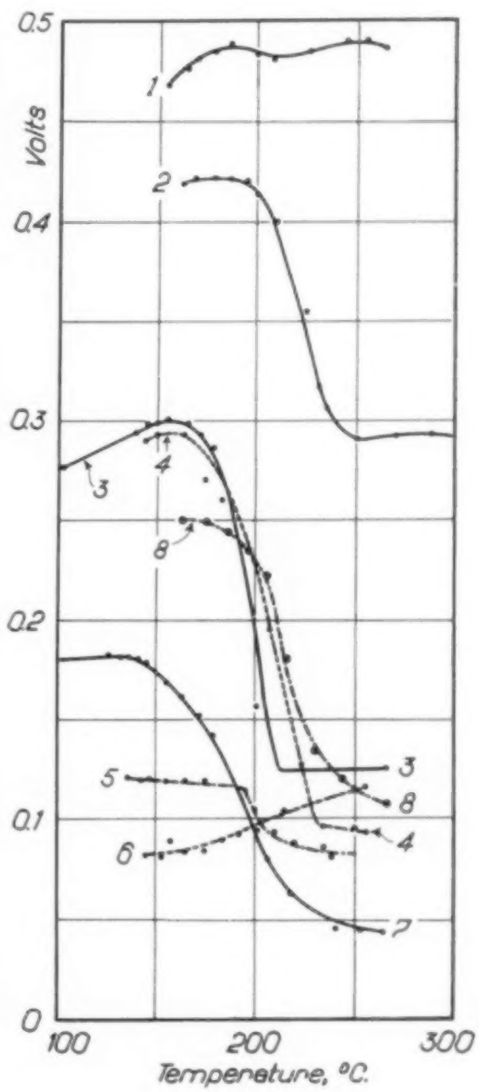
No. 5; Oil Quenched *No. 6; Brine Quenched* *No. 7; Quenched and Tempered* *No. 8; Austempered*

Characteristics at 250 to 150° C. Were Studied

structure, with a general tendency in this series toward refinement of the inter-lamellar distance. The sample quenched in brine is largely martensitic. In the one quenched and tempered sample (No. 7) distinctly lamellar elements are visible. Likewise, the austempered structure has some lamellar elements, but a tendency toward spheroidization is undeniable.

The graph shows the results of the magnetic investigation. The curves are numbered according to the various heat treatments, and are plotted from right to left, as the slightly heated sample cools.

The magnetic "cementite wave", as I call it for the purpose of this publication, is not developed in the spheroidized sample (1); under the conditions of the experiment the relatively large rounded particles of cementite do not change much in magnetism as they cool from about 275° C. to 150° C. The cementite wave becomes very pronounced in the furnace cooled sample (2); a large magnetic residue exists above 250° C., possibly



Magnetic Behavior of 1.05% Carbon Steel in the Various Microstructural States Shown Above, During a Slow Muffle Cool From About 275° C. to 150° C.

due to the massive cementite in the sample; the large increase in magnetism between 250 and 200° C. (the cementite wave) may also largely be due to the more finely divided cementite in the pearlite.

The air cooled samples (3) and (4) show a powerful cementite wave, and a small magnetic residue. The oil quenched sample (5) is quite different; it produces a shallow wave, and an even smaller magnetic residue. The brine quenched sample (6) shows no longer any cementite wave, pointing to the complete absence of this constituent as quenched and after reheating to about 275° C. Both the tempered and the austempered samples (7) and (8) however show again a marked wave, and inferentially a considerable amount of fine cementite. The austempered sample, though mechanically harder than the brine quenched and tempered one (C-49 as against C-45), is magnetically distinctly softer. The cementite wave of the austempered sample is similar to the waves obtained in the

air cooled samples, although the hardness figures differ widely (Rockwell C-49 as against C-31 and C-34).

These tests have perhaps a special interest, because they tend to show that it would be a mistaken idea to consider lamellar sorbite and/or troostite (as represented by the oil quenched sample No. 5) merely as a complete replica, on a finer scale, of lamellar pearlite. The type of distribution of the cementite must differ to a degree more marked than generally realized.

O. A. TESCHE

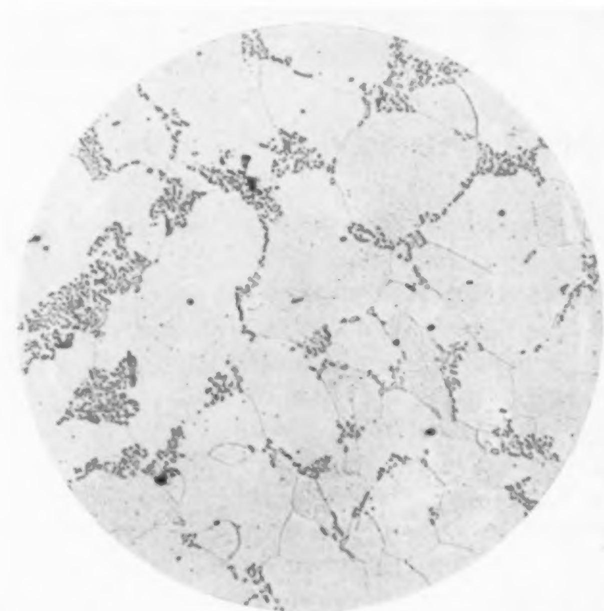
Changes in Microstructure
of still tubes in service

Special letter to METAL PROGRESS
by ROY W. MOORE
Metallurgist
Socony-Vacuum Technical Service Laboratories

GREENPOINT, BROOKLYN — Some interesting structures have recently been discovered in refinery tubes, withdrawn from high temperature service, and a note about them may prove to be a useful supplement to the information presented by Messrs. Wright and Habart on still tubes in the November and December issues of METAL PROGRESS.

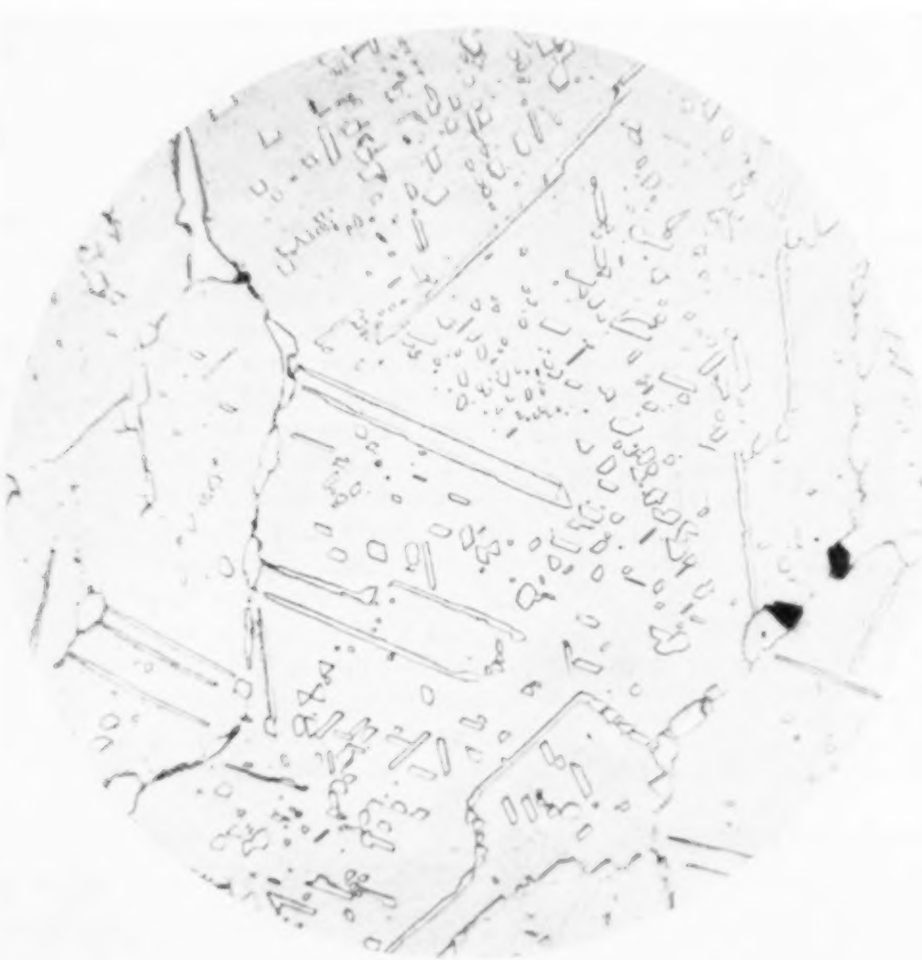
A fuller statement of the formation of graphite in low carbon steel, noted in the November issue, page 577, may be found in an article in 1935 *Transactions* of American Institute of Mining and Metallurgical Engineers by A. B. Kinzel and the present writer. It should be emphasized that the change from pearlite to cementite to graphite is not always to be found in low carbon tubes even after *very* long life in high temperature service. The small micro

Completely Spheroidized Pearlite in Low Carbon Still Tube After 70,000 Hr. Service. Magnified 200 diameters; etched with nital

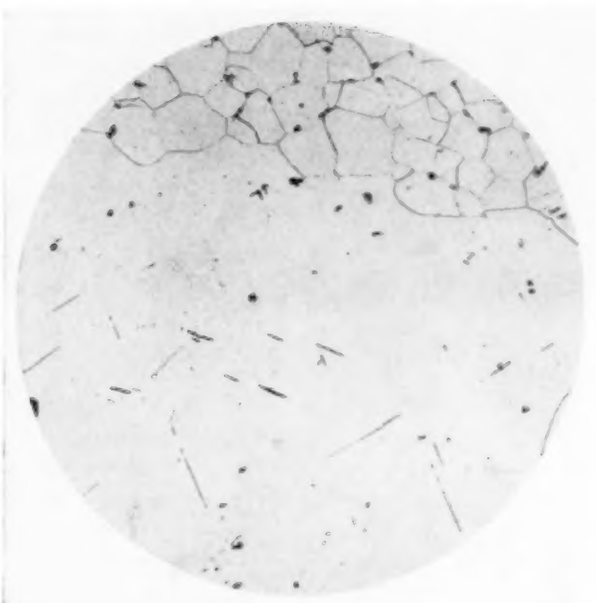


shows, for instance, complete and fine spheroidization of pearlite in a tube withdrawn after 70,000-hr. or 10 years of service. This tube was removed because the wall thickness had been reduced by corrosion or erosion.

Intermediate stages in the spheroidization have also been found in other low carbon tubes, where the pearlite areas contain one or two small crystals of cementite, or have entirely been replaced by a single particle. A middle stage of the same change



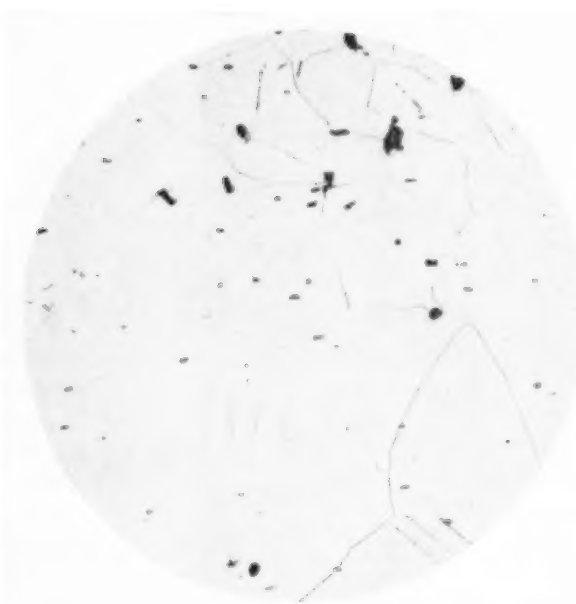
Interesting Concentration of Carbides Near Center of 18-8 Still Tube Wall, and Arrangement Along Geometric Planes of Metallic Crystals. Outer surface of tube was almost free of carbide. This still tube had split in service, probably due to overheating. Magnified 750 diameters



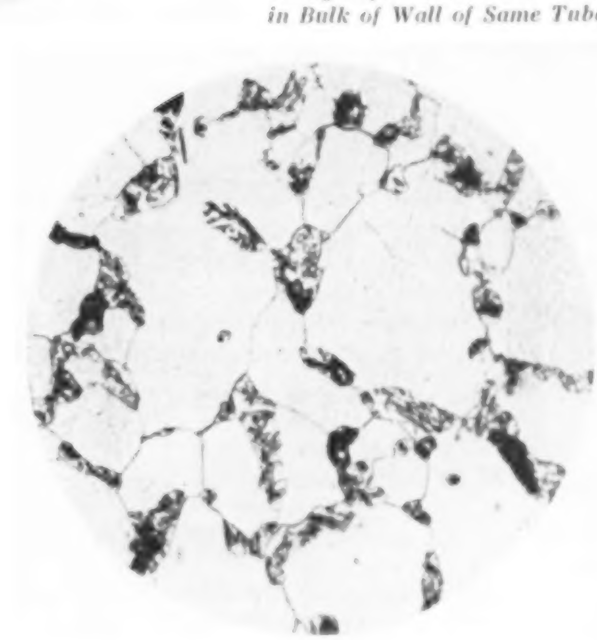
In regions exposed to the flame it will be noted that large ferrite grains adjoin normal sized grains and that a needle-like constituent is present. It was the first impression that this constituent was a nitride. Chemical analysis of this layer of metal, however, indicates that this is not the case. It may be noted also in one of the figures that the carbides have arranged themselves in long parallel stringers (sheets) in the large ferrite grains.

A further interesting set of carbide structures was encountered in the examination of one of the earlier 18-8 still tubes which had failed by splitting. The regular orientation of the carbides in this metal is rather striking, as is shown in the large view on the opposite page. The concentration of carbides shown was found near the middle of the wall thickness; outer edge of the wall contained the austenitic 18-8 structure. The inner edge of the wall contained a very high concentration of carbides. We do not have a complete service record of this tube; however, it is believed that the failure encountered and the observed metallurgical condition were due largely to an overheating of the tube.

R. W. Moore



Structure of Exterior of Still Tube (Low Carbon Steel With 0.5% Molybdenum) Where Flame Impinged. Magnified 200 diameters. Note sharp demarcation of grain growth. Parallel sheets of carbide appear dimly as white lines in the large grain in lower left quadrant of middle micro. Dark "needles" originally thought to be nitride, but chemical analysis lends no support to this idea



Partly Spheroidized Pearlite in Bulk of Wall of Same Tube

may be seen in the lowest view on this page.

It might be added at this time also, that from examinations made of low carbon steel tubes containing 0.5% of molybdenum, we have not noted any cases of graphitization. Some rather unusual structures have been noted in a few such steels, and a group of three micros is shown of the structures in a single tube. The upper two show the structure of the metal near the outside wall of the tube, a condition which penetrates the metal to an extent of about 0.10 in. It does not extend all around the tube but is present on the side of the tube which has been exposed to the flames. The lowest view in the group shows a pearlitic or partially spheroidized pearlitic structure, which is that encountered throughout the remainder of the wall thickness.

HARDENABILITY

(Continued from page 263)

Hyper-eutectoid or carburized alloy steels involve the combined uncertainties of alloy effects and of the effect of carbide form and distribution prior to hardening. Here retained austenite also becomes an important consideration.

The effects of excess amounts of the strong deoxidizers, such as aluminum, zirconium and titanium, need further study. This might of course be considered a phase of the alloy problem except that these elements, when used primarily as deoxidizers and grain refiners, are usually present in such small amounts that they are not recognized as alloy elements.

It is thus seen that hardenability testing is still necessary in many cases. Satisfactory tests, of a quantitative nature, have been developed in which "hardness" after quenching is measured by one of our standard methods, usually on the Rockwell C scale. These tests will undoubtedly continue to be used, but it is to be hoped that as more information is accumulated the need for their use (except for research purposes) will decrease.

Since hardenability testing is now comparatively simple and accurate, it might be asked why there is any great need to predict hardenability from other information. The answer is that it is necessary for the present economy of the steel producer, and hence ultimately of the consumer, that the destination of a heat of steel be known with considerable certainty while the ingots are still in the soaking pits. If hardenability could not be predicted from grain size and analysis, actual hardenability tests would have to be made on the very rapidly processed product of small ingots, which would be costly, and even so the results might not be any more accurately indicative of the final commercial product than the predictions which we can perhaps learn to make from other more rapid and economical tests.

We have for a long time been solving our practical problems in the hardening of steel in an empirical way. Over the past 20 years or so, in particular, we have found qualitative answers to many of our questions. We have recently entered a more quantitative or exact phase of the study, and have already achieved enough progress to be practically useful. Remaining problems are truly complex and it is not to be expected that their solution will come without much additional experimental work and even mathematical treatment. The goal is worth while, and its continued pursuit will make the hardening of steel still less an art and more in the nature of an engineering science.

PERSONALS

Hilary A. Raab has accepted the position of metallurgical engineer for the Chile Exploration Co., Chuquicamata, Chile.

C. C. Edelen, formerly sales engineer, Chicago district office, Surface Combustion Corp., has been made Syracuse district manager.

William B. Scott, formerly sales and metallurgical engineer for Detroit Electric Furnace Co., is now research and development engineer on powder metallurgy, Metals Refining Co., division of the Glidden Co., Hammond, Ind.

Appointed assistant to general manager of sales, Vanadium Corp. of America: **John W. Lohnes**, formerly in the Chicago office.

Francis J. Herman has been made assistant chief metallurgist, Edgar Thomson Works, Carnegie-Illinois Steel Corp.

W. A. Saylor has been transferred from the metallurgical department, Ohio Works, Carnegie-Illinois Steel Corp., Youngstown, to the Duquesne Works as assistant chief metallurgist.

George Sachs, prominent European authority on physical metallurgy, has joined the faculty of Case School of Applied Science, Cleveland.

Frank Sherman is now with A. F. Holden Co., Chicago.

C. W. Heppenstall, formerly president and treasurer of the Heppenstall Co., has been made chairman of the board of directors, and **R. B. Heppenstall**, formerly vice-president and general manager of sales, has been elected president.

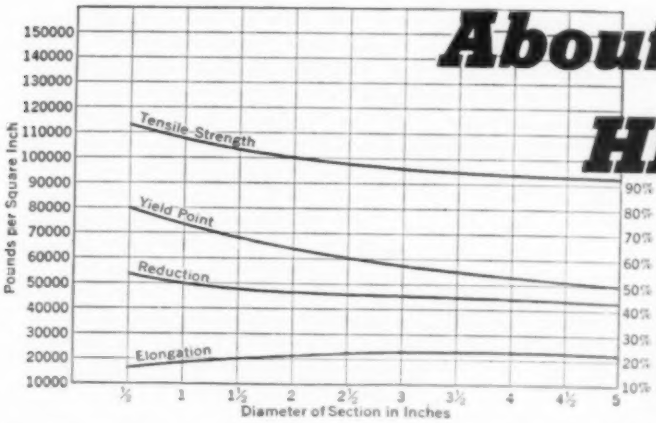
Frank D. Winslow has left Republic Steel Corp. to become district sales manager for Jones & Laughlin Steel Corp. with offices in Houston.

Harold J. Elmendorf has transferred from U. S. Steel Corp. research laboratories and is now research metallurgist for American Steel & Wire Co., Worcester, Mass.

Richard P. Evans has been transferred from the New York office of Wm. Jessop & Sons to the newly opened Chicago office, as district manager for the midwestern territory.

Robert K. Kulp, formerly research metallurgist of Lukens Steel Co., is now research metallurgist for Timken Roller Bearing Co., Steel and Tube Division, Canton, Ohio.

Albert Portevin, of France, veteran contributor to **Metal Progress's** foreign letters department, has been made an honorary member of the American Institute of Mining and Metallurgical Engineers.



This curve shows how physical properties of an S. A. E. 1045 steel fall off as size of part is increased. Oil quenched at 1500 deg. F.; drawn at 1000 deg. F.

About size in HEAT TREATING

Sometimes liquid quenching should not be used

In liquid quenching of steel parts, the size or mass of the part has an importance that is sometimes overlooked.

What is the effect of size? As size of a part is increased, the effectiveness of a liquid quench decreases. The curve above illustrates this. Also, as size is increased, it becomes increasingly difficult to secure a reasonable uniformity of properties throughout the part.

For small and medium-sized parts. In general it is possible to secure reasonably uniform properties in parts up to about eight inches thick provided the larger sizes are tempered or drawn to a high temperature after quenching. Liquid quenching is, therefore, recommended. However, it is important that size be considered in selecting the steel, for it is unreasonable to expect the same combination of properties in a five-inch part as would be developed by liquid quenching a one-inch part of the same material. To meet particular physical values, it may be necessary to select a steel richer in hardening elements.

For large parts. Generally, when wall thickness of a part exceeds about eight inches, it is better not to liquid quench. A low drawing temperature, in an attempt to develop high strength, may not relieve internal stresses and will not develop desirable uniformity. As a consequence, the part may be in worse condition for highly stressed service after the quench and draw than before.

Recommended practice for large parts. If the design of a large part cannot be modified (as, for example, using a hollow instead of a solid forging), it will usually be more satisfactory to select a steel suitable for some type of normalizing and annealing treatment. These treatments will develop most reliable and uniform physical properties in large parts, even though they will not develop the high strength that could be obtained by liquid quenching a small part of the same chemical composition.

When in doubt, ask for advice. Bethlehem metallurgists have had wide experience with heat treating both large and small parts. This experience may provide the solution to your problems. Requesting this service entails no obligation on your part.

BETHLEHEM STEEL COMPANY

BETHLEHEM STEEL

PERSONALS

Transferred: **Walter E. Unverzagt** from U. S. Steel Corp. Research Laboratory to metallurgical department, National Works, National Tube Co., McKeesport, Pa.

W. B. Lair is now welding engineer, York Safe and Lock Co., York, Pa.

Leo J. Gould, chairman, Baltimore Chapter, has been transferred to the Bethlehem plant of Bethlehem Steel Corp. Vice-Chairman **J. W. Miller** will fill out the term as chairman.

K. R. Knoblauch, Philadelphia district sales manager for Brown Instrument Co., has been made assistant general sales manager for Minneapolis-Honeywell Regulator Co.

Presented the Sylvanus Albert Reed award for 1938 of the Institute of the Aeronautical Sciences: **Alfred V. de Forest**, professor of mechanical engineering at Massachusetts Tech.

Promoted by Canadian Westinghouse Co.: **C. H. Mitchell**, past chairman, Ontario Chapter, to works manager; **J. T. Tiplady** to general superintendent; **F. S. Strickland** to superintendent of the electrical division.

Promoted: **Ralph E. McGee** from chief metallurgist, Farmall Works, International Harvester Co., to assistant chief metallurgist for all International Harvester factories.

Edward P. Geary, midwestern sales manager for Rustless Iron & Steel Corp., has sailed for London to make a survey preliminary to establishing a stainless steel plant. **R. L. Springer** will take over Mr. Geary's duties in the Chicago territory.

Thomas L. Moore has resigned as field metallurgist for Republic Steel Corp. in Chicago and is now in sales service work for Rustless Iron & Steel Corp.

Mark M. Miller is now employed at the South Works, Carnegie-Illinois Steel Corp.

K. L. Wilson has been transferred from the Philadelphia sales office of Minneapolis-Honeywell Regulator Co. to represent the Brown Instrument Division in Indiana and northern Kentucky as industrial manager.

R. G. Minarik has been added to the staff of the department of mechanical engineering, Armour Institute of Technology.

Harry M. Roop is now with Huffman Wolfe Co., Philadelphia, doing cost and purchasing work.

Ralph Hare has been appointed New England representative of the Electro-Alloys Co. with headquarters at West Hartford, Conn.

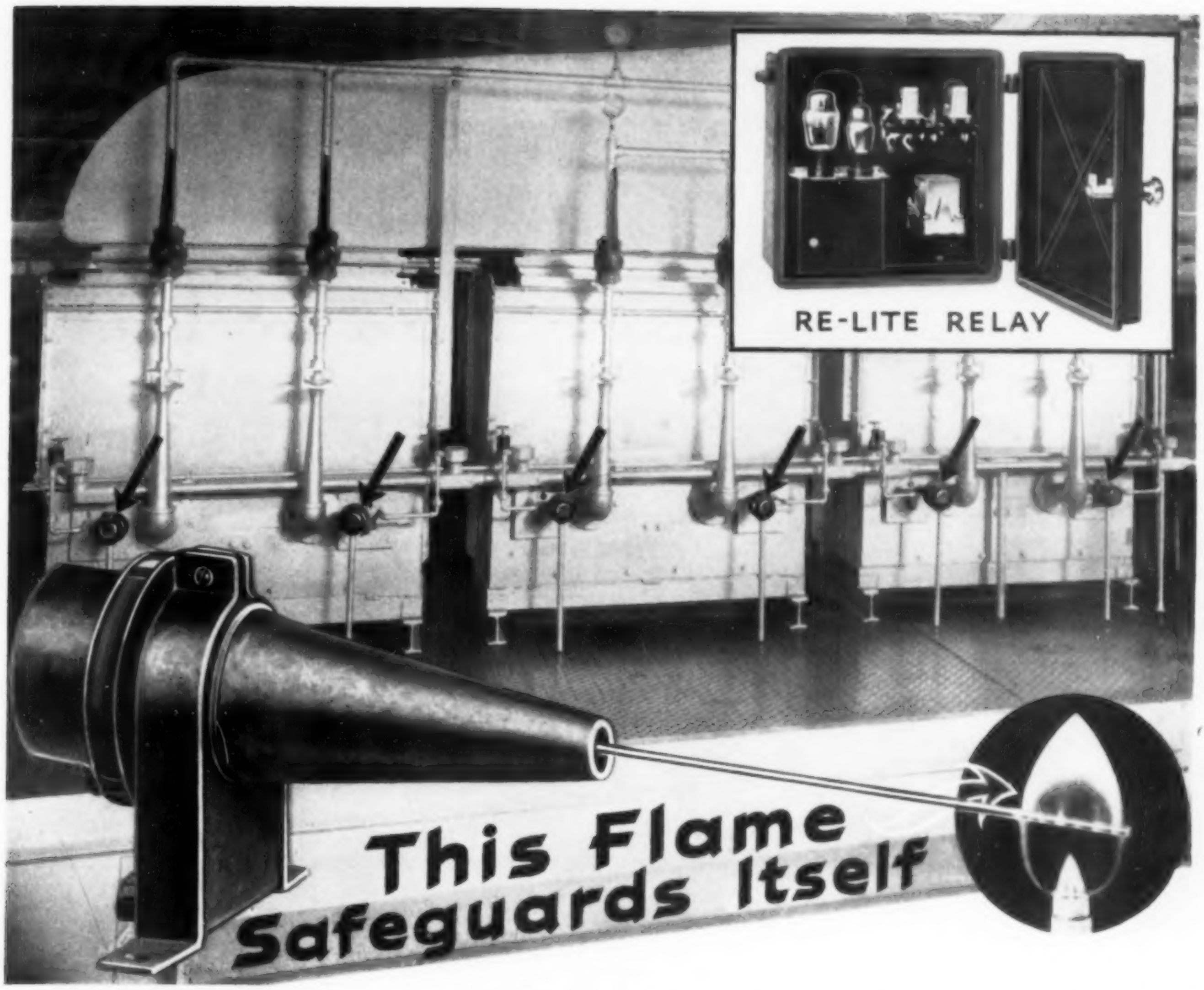
(Continued from page 253)

such a size as to require several men for handling; many such arbor supports, tool holders, dividing heads, gear case covers and special fixtures, are now made as high strength aluminum alloy castings, and thus greatly facilitate handling.

The application of aluminum to portable tools has been expanded materially since the introduction of the newer high strength casting alloys. Rail benders, mechanical and hydraulic jacks, blocks, and sheaves, incorporating many cast aluminum parts, are sufficiently lighter to make them more readily portable and more easily put into position for use. Air driven and electric hand tools are much less fatiguing to the operators when constructed of aluminum castings.

Electrical characteristics of aluminum account for its increasing use for many applications. Large automatic spot and seam welding equipment uses high strength aluminum alloy castings for such parts as require high electrical conductivity and whose operation requires light weight. The non-magnetic characteristics are also utilized where local heating due to eddy currents must be avoided. Stator frames, frame ends, and brush holders for large motors are made as aluminum alloy castings with a substantial reduction in the final weight. Connector boxes for underground cable lines, oil switch housings for high tension lines, cable and bus bar clamps, and instrument and meter cases of aluminum alloy castings are common. Conductor bars, end connectors and fans are commonly cast integrally with the rotor stampings for small motor work; this cuts production cost and eliminates changes in machine set-up when different electrical characteristics are required —high or low conductivity being achieved by merely selecting the correct aluminum alloy.

This list could be expanded further and many applications not yet of commercial importance might be added. The versatility of aluminum is, however, already well illustrated, as are the various advantages that have been gained by its use. With a still more general appreciation of the variety of properties afforded by these aluminum alloys and the fabrication economies through the various casting processes, a still wider application of these materials is to be expected.



FLAME ELECTRODE

Arrows in above illustration point to Six Protectoglo Flame Electrodes on gas-fired enameling oven in the St. Paul plant of a well-known automobile manufacturer.

THE Brown Protectoglo System gives you positive protection against pilot flame failure. It operates on the principle that a flame conducts electric current — the circuit breaking and fuel valves closing the instant the flame is extinguished. It is safe . . . sure . . . dependable . . . approved by the *Associated Factory Mutual Fire Insurance Companies.*

The Brown Protectoglo System consists simply of a Flame Electrode, a Relay with either a Cut-Off or Re-Lite Model and suitable control valves in the pilot line and main fuel supply. The Protectoglo Flame Electrode mounted in a porcelain insulator, as illustrated above, is always in direct contact with the pilot flame.

The circuit used in this system is the result of intensive and thorough research. Not only does the system provide complete and instantaneous shutdown in the event of flame failure, but it also provides *Continuous Protection Against Grounding of the Flame Electrode.* The components of the electronic circuit itself make the system entirely immune to failures that would result in unsafe operating conditions.

Complete data supplied on request. Write THE BROWN INSTRUMENT COMPANY, *a Division of Minneapolis-Honeywell Regulator Co.* 4503 Wayne Avenue, Philadelphia, Pa. Offices in all principal cities. Toronto, Canada: 117 Peter Street—Amsterdam-C, Holland: Wijdesteeg 4—Stockholm, 16, Sweden: Nybrokajen 7—London, England: 70 St. Thomas' Street, S. E. I.

Advantages of the Brown Protectoglo System

1. Cuts off fuel supply the very instant a flame fails.
2. Temperature and Humidity have no effect on the operation of the Protectoglo.
3. Continuous protection against grounding of electrode.
4. Used with any kind of gas and any type of flame. No other combustion safeguard operates within such a wide range of flame resistance values.
5. Safety of operators and equipment through complete avoidance of explosion hazards.
6. Flexibility permits any convenient tie-up with other control devices — automatic or manual start-up, electric ignition, time delay sequence for purging, or any other operation desired.
7. The Protectoglo is unaffected by flame fluctuation.

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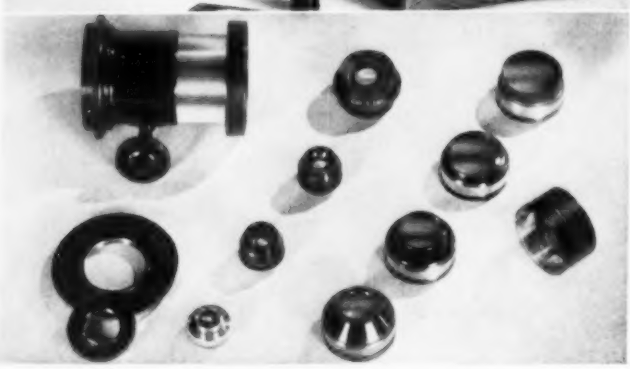
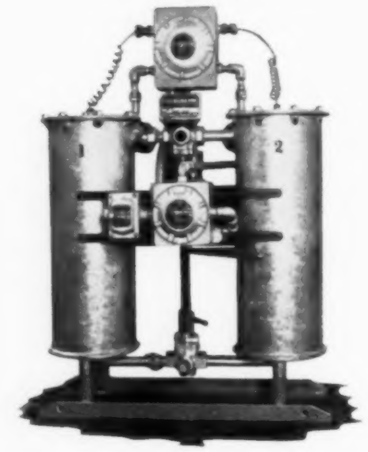
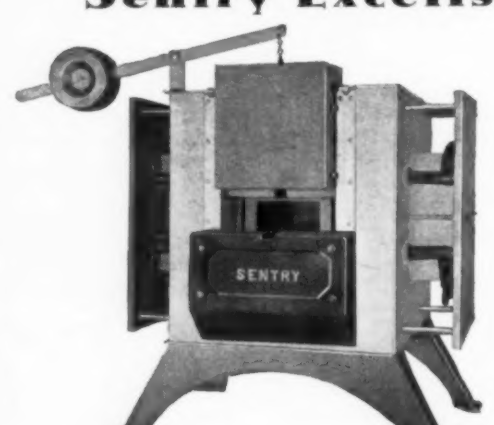
COMBUSTION SAFEGUARD
Protectoglo SYSTEM






SENTRY

NOTES ABOUT AUTHORS

Adolph O. Schaefer's employment was varied until he began with the Midvale Co. back in the fall of 1922 in what was then called the "micro lab". (Spring of that same year had seen his graduation from University of Pennsylvania with a B.S. in chemical engineering.) From the micro lab he became assistant engineer of tests and in 1937 engineer of tests and inspection. Mr. Schaefer has long been active in the Philadelphia Chapter, serving as a very capable secretary-treasurer for seven years and currently as chairman. His principal interest outside of steel, A.S.M. and family, is in vegetable gardening and fishing. Schaefer's article in this issue on large forgings is by no means his first technical contribution to and other publications — **Metal Progress** readers will no doubt recall with a chuckle "Those Hopkins Bars; What Happened on Night Shift" published in June 1935, which bore more than a few earmarks of expert short story writing.

H. J. Rowe is a native Clevelander with a B.S. degree in physics from Case School of Applied Science in 1927. He has been with Aluminum Co. of America in the foundry division at Cleveland ever since. His article on page 249, taken from a paper presented before the Western Metal Congress last spring, reflects his interest in technical control and development work in connection with aluminum alloys and their methods of fabrication and applications. Committees of the American Foundrymen's Association and the American Society for Testing Materials on various aspects of aluminum founding have benefited by his active participation.

Adolph O. Schaefer

H. J. Rowe

PIT CORROSION

(Continued from page 248)

Suppose the metal is immersed in a chloride solution and contains a sharp crack or has some substance lodged on it. Circulation of the solution is much more restricted at the bottom closure than at the open top, and only a little general corrosion will be necessary to exhaust the oxygen at the bottom, where corrosion products accumulate. This condition of higher oxygen concentration at the outlet than at the bottom will tend to make the mouth of the pit cathodic to the bottom. Flow of electrons then starts from the bottom through the metal to the top and to the surface surrounding the opening, which region becomes negatively charged. Ferric chloride existing in solution near there as a corrosion product (ferrous chloride, the original product of general corrosion, has oxidized to ferric chloride) will be ionized, and chlorine ions are repelled from the cathodic surface and attracted to the cathode at the bottom, there to meet with iron going into solution as ferrous iron (Fe^{++}).

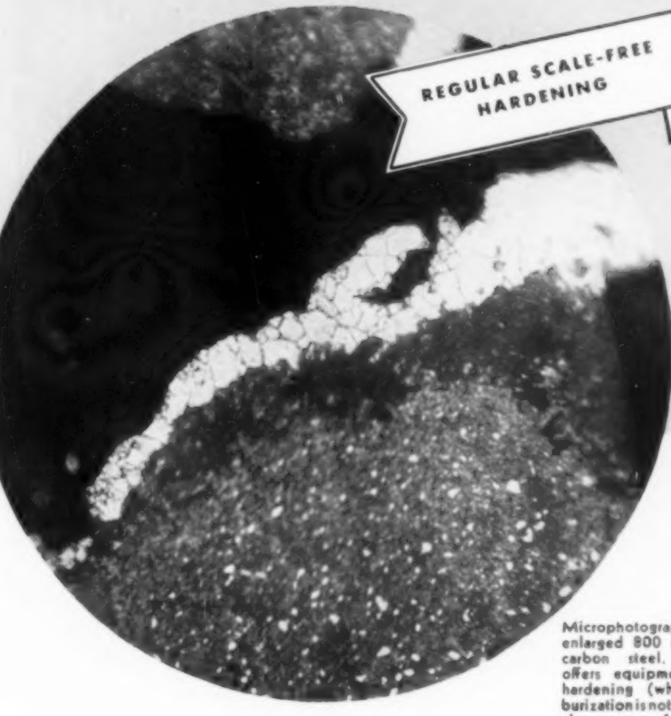
It will be noted that this mechanism assumes that the pit is already located by some flaw or contact, that action is started by a difference in oxygen concentration, that the iron goes into solution in the pit as ferrous chloride, that the oxidized ferric chloride outside is reduced to ferrous chloride at the passive surface, but is free to diffuse away, whereas the ferrous iron forming at the cathode is mostly retained in the pit. Even though the corroding solution be sodium chloride and the corrosion much slower, electrochemical reactions are indicated by Dr. Uhlig showing that the iron chlorides become eventually the prime corroding reagents. He concludes that electrolytic action causes pitting at a speed which is related to the potential difference between the active surface (pit) and the passive surrounding surface, and also to the presence of depolarization phenomena. Iron chloride is so active because of the lack of any depolarizer — the products of corrosion instead of blanketing the surface are soluble and have high rate of diffusion, thus permitting a high current density in the cell and a high rate of corrosion.

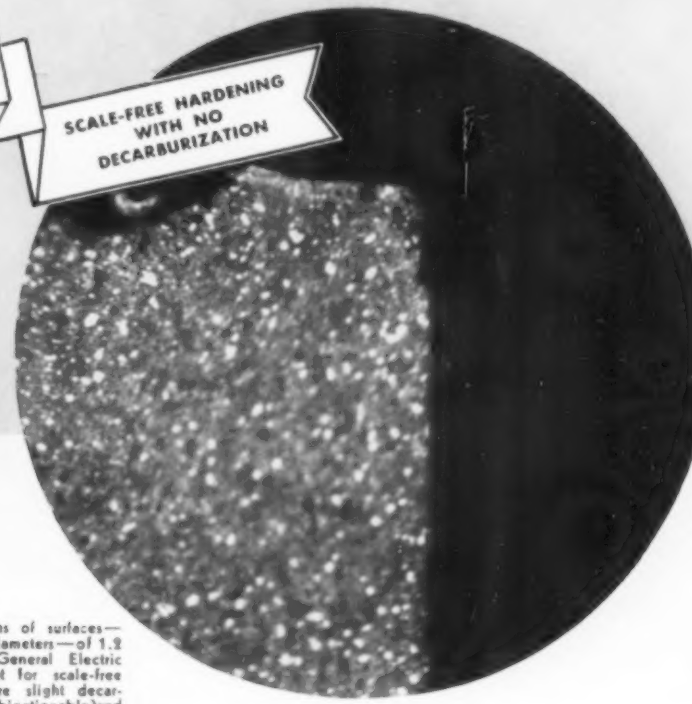
Ingenious apparatus was devised to measure the action of various combinations of solutions on stainless steel surfaces. Others utilized a stainless steel cylinder in a porous cup, immersed in an electrolyte with a battery current; this model of a pit enabled the investigator to sample and analyze the solutions existing in a growing pit. Other experiments measured the "threshold potential", a term meaning the applied emf. necessary to start reaction between metal and anion like Cl^-, Br^- or I^-. "Threshold potential" is preferred by Dr. Uhlig

(Continued on page 306)

HERE'S PROOF—

G-E SCALE-FREE HARDENING WITH NO DECARBURIZATION





Microphotographs of surfaces—enlarged 800 diameters—of 1.2 carbon steel. General Electric offers equipment for scale-free hardening (where slight decarburization is not objectionable) and also—now—for scale-free hardening with no decarburization

HERE we announce some conclusions from thorough tests made in the G-E Industrial Heating Laboratory.

Hardening steel without decarburization—as well as without scale—is now practical and economical by means of a newly developed General Electric process.

Our engineers, having made, studied, and checked hundreds of microphotographs of samples taken from actual production, are now confident that the following steels are hardened without decarburization by the new process:

SAE No.	2512	3135	3140	6150
	3312	7135	5140	1060
	4615	1040	6140	9260
	4130	2340	4150	1090
				52100

But this list is *not complete.* Tests now being made indicate that soon we may be able to say with similar confidence that this process can be applied to an even wider range of steel.

HOW DECARBURIZATION IS AVOIDED

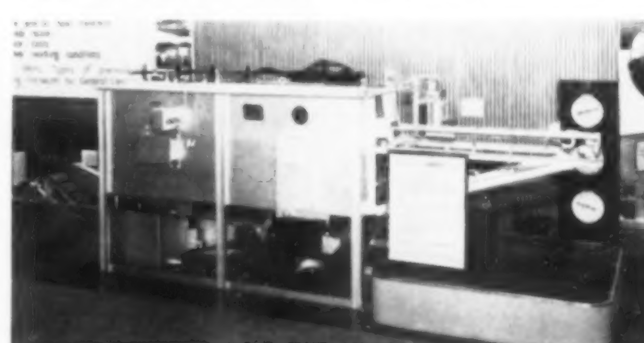
The furnace atmosphere produced for the process is dry and free from CO_2. The furnace, having an entirely enclosed conveyor and a sealed chute for automatic quenching, is completely sealed except for the door opening. This construction assures the maintenance of a dry, CO_2-free atmosphere and makes possible the large-scale production of scale-free-hardened parts without decarburization.

COST OF NEW PROCESS BUT LITTLE MORE

The cost per pound treated is little more than that for ordinary scale-free hardening, in which some decarburization is often encountered. You will find the new process worth more than the extra cost, however, since with it you can give practically any product the benefits of scale-free hardening—clean, unmarred surfaces; uniform hardness; finish to size before hardening; and less handling.

ASK FOR MORE INFORMATION

If you are interested in this new process that offers so much, get in touch with the nearest G-E sales office. Its heating specialist has the full use of the Industrial Heating Laboratory at his disposal, so he is well qualified to help you with your particular problem. General Electric, Schenectady, N. Y.



In 1937, at the National Metal Exposition, General Electric introduced this furnace for scale-free hardening. Now it can be used in a new process to harden steel without decarburization.

GENERAL ELECTRIC PROVES FURNACE PERFORMANCE WITH LABORATORY TESTS

GENERAL ELECTRIC

160-80

for better welds *and faster welding*

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● Page Hi-Tensile "F" is an all-purpose electrode with a reputation for reducing fabrication costs. It is perfectly suited to construction, maintenance, production work. It saves a lot of time on high-speed, single-pass welding and on jobs in Cor-ten, Cro-man-sil, H-T-50 and other new alloy steels.

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PIT CORROSION

(Starts on page 247)

over "film break-down potential", for he rejects the hypothetical action of a protective film because platinum, which no one supposes has or needs a protective oxide layer, has a threshold potential of 1.34 volts for Cl^-, about equal to 18-8 with molybdenum and more than twice that of plain 18-8 under similar test conditions. He concludes that if the electrolytic cells set up on the surface of any passive surface have a larger emf. than the threshold potential (as ferric chloride, cupric chloride, or oxygenated sodium chloride on 18-8) the metal will pit; if the emf. is lower (as tin or titanium chlorides on 18-8), the corrosion will be general.

It was further found that plain 18-8 corrodes in chloride first to ferric ions but almost immediately reverts to ferrous ions and forms pits, while 18-8 Mo corrodes always to ferric ions and wastes away by general corrosion. In others words, 18-8 corrodes in $FeCl_3$ as active metal (Fe^{++}), whereas 18-8 Mo corrodes as passive metal (Fe^{+++}). To the large emf. between passive and active metal surrounding and within a pit in 18-8 is ascribed the rapidity of the action, together with the mobility of the chloride ion already mentioned. On this basis, the function of nickel and chromium in the alloy is to ennoble the passive pit — that is, to give a large emf. between cathode and anodic area in the pit, and thus speed up concentrated attack, once it is started — whereas the function of molybdenum in 18-8 is to stabilize this passive state and prevent its local perforation, rather than to build up a more impervious or persistent oxide layer.

Nature of Passive Surfaces

The very important question of the nature of this passive state is dealt with rather briefly in these reports, but at length in a paper by Messrs. Uhlig and Wulff before the A.I.M.E. It must suffice here to say that since active surfaces of 18-8 are in equilibrium with ferrous ions (Fe^{++}) and passive surfaces are in equilibrium with ferric (Fe^{+++}), the essential difference between active and passive states has something to do with electronic linkages. The authors assume that the chromium atom shares the six electrons in its outer "shells" with as many iron atoms — in other words, six active Fe^{++} atoms become passive Fe^{+++} by sharing the electrons with one chromium atom. On this basis active iron alloy would become a passive iron-chromium alloy when it contained one chromium atom for every six iron atoms — that is, at 16% Cr by weight. This checks the actual situation fairly well.

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Read what one builder says about "Carbofrax"

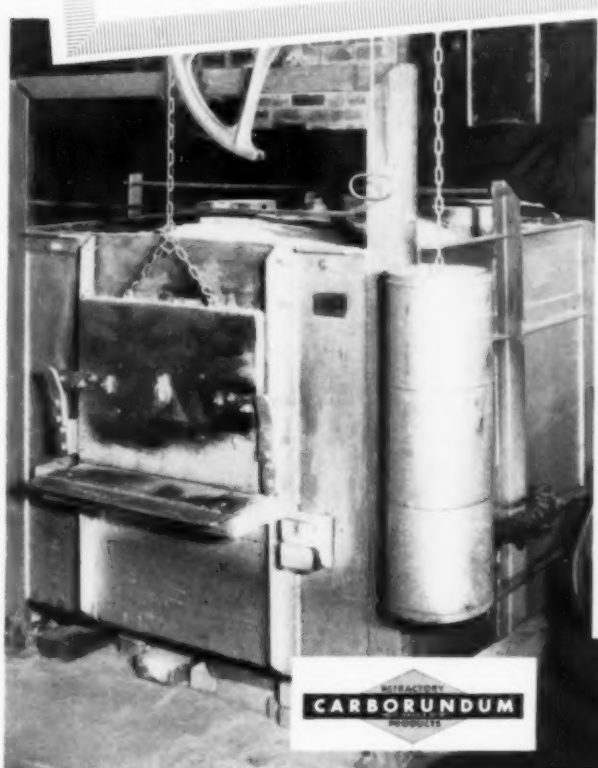
"We use 'Carbofrax' materials to obtain rapid heat transfer. We find it stands up in service--" says The M. K. Epstein Company, builders of Dempsey and Gilbert, and Barker Furnaces.

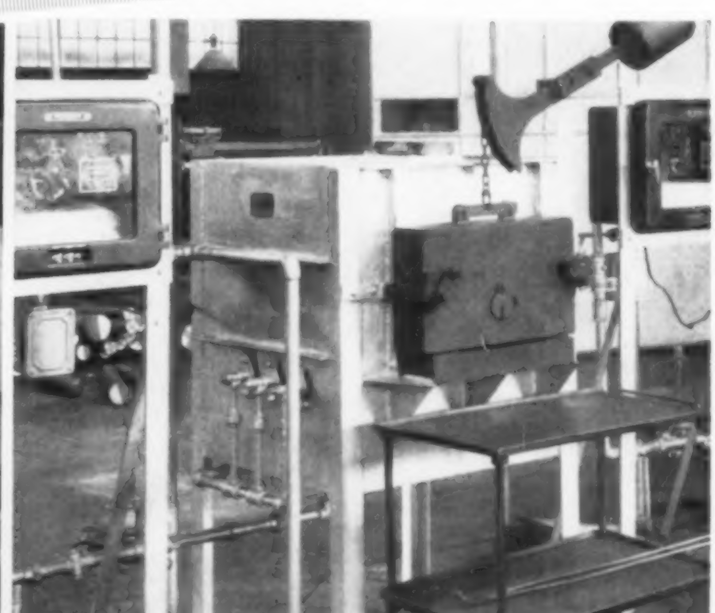
Illustrated are two of the many furnaces utilizing "Carbofrax", built by this well known, progressive firm of Springfield, Mass.

Its reputation for building high quality furnaces is well founded on progressive engineering and on the specification of the highest quality materials for furnace construction.

The M. K. Epstein Company has used "Carbofrax", the Carborundum Brand Super Refractory, for many years and regularly specifies it in furnaces where rapid heat transfer and resistance to high temperatures are required.

The acceptance of "Carbofrax" as a standard by such a leader in the furnace building industry is an indication that this super refractory can reduce costs and speed production in your heat treating shop.





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